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JOURNAL

of the

AMERICAN WELDING SOCIETY

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AMERICAN WELDING SOCIETY

ESTABLISHED 1919

JOURNAL

Volume 9 December, 1930 Number 12

New Size Journal

Beginning with the January issue, the Journal of the American Welding Society will be published in the standard 9 in. x 12 in. size.

This larger size Journal has been adopted by practically all of the major engineering and scientific organizations. The Executive Committee felt that this standard size offered a number of advantages. It will permit larger illustrations and offers economies to advertising departments through the use of standard layouts. In turn, this will, no doubt, increase the revenue from advertising and therefore permit the publication of a greater amount of material.

Lincoln Prize Competition

The Second Lincoln Arc Welding Prize Competition recently announced by that company is creating a great deal of interest as measured by a number of inquiries being received from all parts of the world. This second prize competition was announced about two months ago and is designed to stimulate designers and engineers in every line of industry to consider the application of arc welding to the manufacture of their products. 41 prizes totalling $17,500 are to be given away. The contest will close October 1, 1931.

V. D. I. Publication on Welding

On the occasion of the Annual Convention 1930 of the Verein Deutscher Ingenieure (Society of German Engineers) there were read before the Special Committee on Welding various papers dealing with Arc and Oxy-Acetylene Welding.

The editors of the "VDI-Zeitschrift" (Journal of the Society of German Engineers) have decided to publish them in a special number of their journal, entitled "Welding Engineering."

The following subjects are extensively treated the text being supplemented by numerous illustrations:

Theory of the Electric Arc applied to Welding.

Fatigue Strength of Welded Steel Joints.

The Significance of the Welding Depth in Arc Welding and how to improve it.

The Influence of Nitrogen on Arc Welding.

Progress of Welding in Steel Construction.

Importance of Oxy-Acetylene Welding to Apparatus Construction for the chemical industry.

Progress of Oxy-Acetylene Cutting.

Questions of Safety in Connection with Oxy-Acetylene Welding.

Arc-Welding with Three-Phase Current.

Conference on Welding

The Engineering Extension Department of Purdue University held its Sixth Annual Conference on Welding at Lafayette, Ind., on December 10-11, 1930.

This two-day educational conference dealt with the latest developments in application of welding as applied to manufacturing operations and maintenance problems.

Structural Welding Gains

(Reprinted from December 13, 1930, issue of "Electrical World")

Precedents which have been hampering the building industry for years are gradually giving way. Welding of building structures is gaining ac-

ceptance. Five cities, including New Orleans, allow it when performed according to the American Welding Society code, and 88 other cities have adopted a similar code. According to a questionnaire sent out by the Society, four concerns alone have used welding in constructing 91 buildings, involving thousands of tons of steel. Even bridges are being welded.

As much as 7 per cent in steel has been saved by welding owing just to the fact that the cross-section does not have to be increased to offset rivet holes. Because gussets are not so essential to welded trusses as riveted types, 14 per cent reduction in steel has often been effected from this cause alone. Furthermore, no slip occurs in welded joints, as may happen with riveted ones, and of course the irritating din of rivet hammers is avoided.

With these advantages of welding there is no logical reason why it should not be adopted more widely for building structures, provided that safety is assured. To this factor major consideration has been given by the group which formulated the American Welding Society code and which knows that any failure of welded structures will be a "black eye" to further extension of this practice. Its specifications of allowable welding materials, design details, permissible unit stresses are all aimed to assure adequate safety factor. But it goes further by requiring the examination of workmen to insure that they will produce uniformly satisfactory welds.

When it is considered that a variety of tests have shown that welds made by carefully selected operators will consistently show unit strengths in shear and tension four times the permissible stresses allowed by the code, the safety of welding seems pretty well protected by that instrument. Especially is this true since, according to numerous tests, visual inspection of welds by trained inspectors will reveal improper welds.

But efforts to develop a simple method of making field tests of welds in place must not relax if the legitimate field of welding is to be opened without further delay.

SECTION ACTIVITIES

BOSTON

The meeting of the Boston Section held on November 14 was held at the plant of the Thomson Gibb Electric Welding Company, Lynn, Mass. Papers on the following subjects were presented: "Welding of Motor Magnet Frames," "Seam Welding," "Flash and Projection Welding as Applied in the Automobile Industry." The speakers were Malcom Thompson, General Electric Company, and W. T. Ober, Thomson Gibb Electric Welding Company. Demonstrations were held on the operation of manual and automatic butt-spot and seam welding machines after the discussion of the papers.

The meeting for December 19 will be held at 715 Tremont Temple, at 7.30 p.m. R. A. Wolff, president, Wolff & Munier, Inc., will speak on "Panel Heating." He will discuss this novel method of heating as applied to the new British Embassy Building in Washington. Motion pictures will be used, showing the constructing and installing of this equipment at Washington.

A joint meeting with the Boston Society of Civil Engineers will be held on January 28, 1931, at which the welding of the new Boston Edison office building will be discussed. Three papers will be presented and motion pictures and lantern slides will be used.

CHICAGO

The November meeting of the Chicago Section was a very successful one. Fred G. Outcault, of the Linde Air Products Company, read a paper on the "Welded Panel Heating System" and showed the motion picture of the installation of this system at the British Embassy. W. V. Emery, of the Harnischfeger Corp., read a paper showing the development of welding applications in the manufacture of heavy duty excavating equipment. This paper was illustrated by lantern slides.

It is planned this year to have dinner meetings, that is, to have the dinner precede the meeting.

CLEVELAND

L. R. Gurley, editor of "Welding," is scheduled to present a paper on

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"The Oxy-Acetylene Process in the Aircraft Industry" at the December 11 meeting, which will be held at the Carnegie Hall, 1220 Huron Road.

DETROIT

"Welding and Fabrication of Industrial Piping" will be presented by Walter J. Thomas of Walter J. Thomas & Company at the December 18 meeting of the Detroit Section. Motion pictures of typical pipe welding applications in this country, and also lantern slides made by Mr. Thomas while superintending pipe welding work in Russia, will be shown. Mr. Thomas will give a very interesting picture of the industrial program of the U. S. S. R.

LOS ANGELES

The November meeting was held at the Engineers Club on the 18th. After dinner motion pictures were shown through the courtesy of Perry F. Backus, local attorney and Cine-kodak enthusiast. Mr. Backus' showing of the Hawaiian Islands in natural colors was quite a treat and the comedies donated by the Eastman Kodak Company afforded considerable mirth.

The local Chairman, W. A. F. Millinger, introduced an unexpected visitor, R. H. Atkinson, past Chairman of the San Francisco Section, who spoke of the activities of the San Francisco Section.

The featured speaker of the evening, Professor Arthur E. Hoare, University of Southern California, spoke on "The Welder's Eyes." Preceding the doctor's talk a picture was shown on the mechanical operation of "How We See." Professor Hoare treated the subject from the welder layman's standpoint.

R. G. Wulf, chemical engineer, continued his lecture on "The Chemistry of the Welding Flame," which centered around the chemical constituents of the welding flame. This is an educational feature which this section hopes to continue.

C. Oatis, arc welder, gave a short outline of the welding of the Dallas Power & Light Company office building, which has just been completely fabricated by arc welding.

NEW YORK

A motion picture entitled "The Span Supreme" was shown to the public for the first time through the courtesy of the J. A. Roebling's Sons Co., at the December 16 meeting. A talk by C. M. Jones of the engineering department of the J. A. Roebling's Sons Co. accompanied the showing of this picture. W. A. Wissler of the Union Carbide and Carbon Research Laboratories, Inc., and A. V. Harris of the Haynes Stellite Company presented a paper which dealt with various applications of hard facing with non-ferrous alloys. This paper was entitled "Hard Facing."

WESTERN NEW YORK

The Western New York Section held its regular monthly meeting at the Statler Hotel, Buffalo, on November 10.

This meeting was addressed by D. H. Deyoe, industrial engineering department of the General Electric Company.

The subject in general was related to the electric welding of structural steel, battle-deck steel floors and a brief outline of recent developments in the application of arc welding in general.

Lantern slides and moving pictures were used. Some of these showed the 14-story building of the Southern California Edison Co. at Los Angeles; the 13-story building of the Boston Edison Co. at Boston and the 19-story building of the Dallas Light & Power Co. at Dallas, Texas. They also illustrated the battle-deck steel floor of the Berkshire Garage at Pittsfield, Mass.

The next meeting will be on December 8. The subject will be "Oxy-Acetylene of Transmission Pipe Lines" by W. R. Ost of the Air Reduction Sales Co.

The meeting on February 9, 1931, will be on the subject of "Arc Welding of Corrosion Resistant Steels" and will be addressed by R. D. Thomas, vice-president of Arcos, Inc.

The meeting following will be on March 9, 1931, on the subject of "Automatic Electric Welding" and will be addressed by G. H. Koch of the Westinghouse Electric & Mfg. Co.

PITTSBURGH

R. Kraus, supervisor of welding inspection, Westinghouse Electric & Manufacturing Company, presented a paper on "Inspection in Relation to Shop Fabrication and the Erection of Welded Buildings, at a meeting of the Pittsburgh Section held last month.

About a hundred people were present, including representatives from the city of Pittsburgh, leading contractors, fabricators and manufacturers of steel.

Mr. Kraus covered selection and training of inspectors, instructions for inspectors and general precautions for the safety of workmen in the erection of buildings. Considerable discussion followed.

A. E. Dittrich, service engineer of the Linde Air Products Company, presented a formal discussion on rapid growth of overland pipe line welding. This was supplemented by two reels of motion pictures on pipe line welding.

The next meeting of this Section will be held on December 17. H. A. Woofter, chief engineer of the Swift Electric Welder Company, will present a paper on "Resistance Welding." P. R. Hawthorne, consulting engineer, will speak on "Welding Heavy Plates and Pressure Vessels."

The January meeting will be arranged as a joint meeting with the Civil Section of the Engineers' Society of Western Pennsylvania. Prof. F. P. McKibben, consulting engineer, will talk on structural steel welding.

In February a joint meeting will be held with the Pittsburgh Section of the American Society of Mechanical Engineers. C. W. Obert, consulting engineer, Union Carbide & Carbon Research Corp., and honorary secretary of the A. S. M. E. Boiler Code Committee, will discuss suitable procedures and processes for the welding of pressure vessels.

EMPLOYMENT SERVICE BULLETIN

Opportunities.—The Society is glad to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN.

Services Available.—Under this heading brief announcements (not more than seventy-five words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period, names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Society's Office not later than the thirtieth of the month if publication in the following issue is desired. *ALL REPLIES should be addressed to the number indicated in each case and mailed to the Society headquarters.*

SERVICES AVAILABLE

A-107. Welder with ten years' experience with electric arc and acetylene on tanks, boilers, sheet metals, etc., desires position in Chicago. Can use own judgment. Am skilled operator.

A-112. Pipe welder desires position. Have had considerable experience on welding pipe and am anxious to become connected with concern that is fabricating pipe, such as steam heating.

A-113. Welder desires position. Have had ten years' experience in general repair and construction work, locomotives, tanks, pipe line welding, etc. Especially interested in structural steel welding. Have also had experience as inspector for Southern California Edison Company's new office building at Los Angeles. Worked on tallest welded building in Dallas. Can furnish references.

Welding Field Joints on a Fourteen-Story Office Building*

By J. Theodore Whitney†

THE structural steelwork of the new office building for the Edison Electric Illuminating Company of Boston has all field connections electric-arc welded. As such it represents the first project of its kind in Boston and was made possible by the building commissioner exercising his discretionary powers under the building law, which allows the use of new materials or methods under such regulations as the commissioner may fix. In this case the requirement fixed was that the consulting engineer, F. P. McKibben, should certify by affidavit that the building, as pertains to the welding, would conform to the stresses and strains required by law, and that at the completion of the welding should certify by a final affidavit that the building does conform.

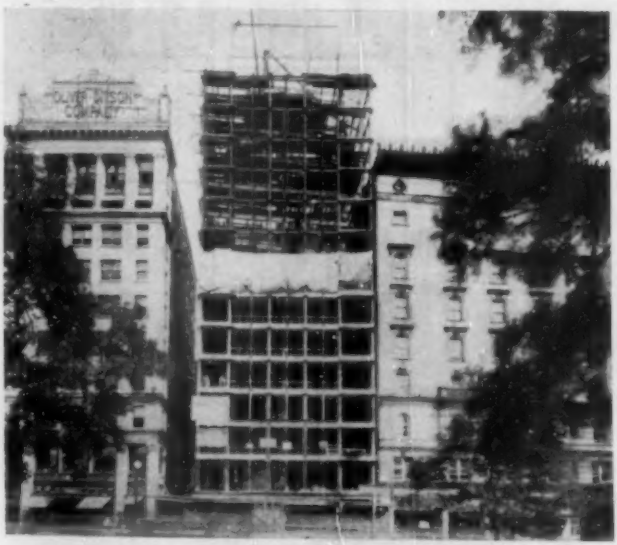

Fig. 1—Shop-Riveted, Field-Welded Frame of New Edison Co. Building in Boston

Some of the results observed, because of the use of welding instead of riveting on this structure, are as follows: (1) Noise of construction of joints in the steel frame were practically eliminated at site of erection; (2) accident hazard was greatly reduced by elimination of dropped bolts and rivets; (3) alterations, made necessary by errors or changes, were

*Presented at Nov. 17, 1930, meeting of the Philadelphia Section, A. W. S.
†President, Whitten-Beekman Engineering Co., Boston, Mass.

more easily made; (4) smaller gussets were required for wind bracing; (5) staging for erectors was more simple and less expensive; (6) fire hazard was reduced due to absence of hot rivets; and (7) connections to support erection derricks were easily and rapidly made as work advanced.

Lease Conditions Affecting Design—The building is fourteen stories high, covering a plot approximately 110 x 58 ft. It contains 1,314 tons of steel, of which 1,050 tons is framed together by welding. Conditions in

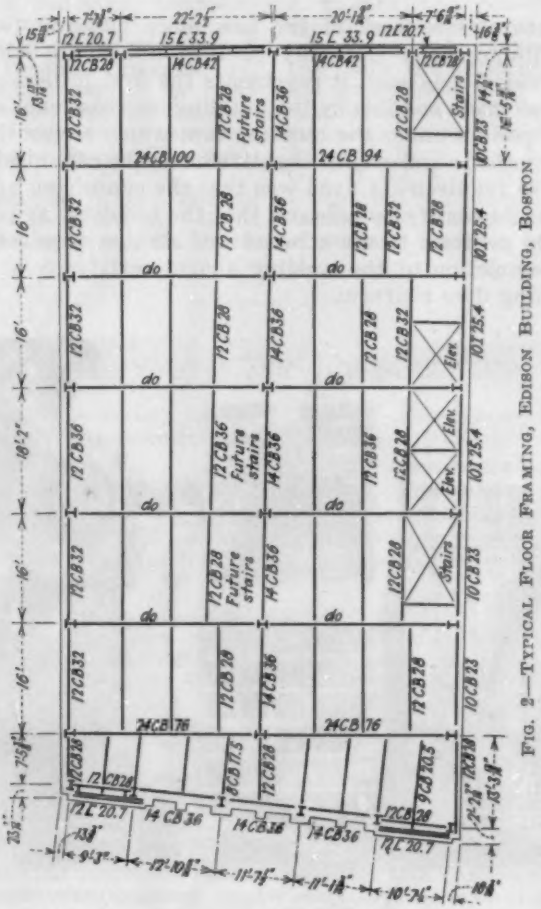

FIG. 2—TYPICAL FLOOR FRAMING, EDISON BUILDING, BOSTON

the leases on the two lots making up the plot required the building to be designed for "any commercial use allowed by the zoning law." This necessitated the use of a 125-lb. live load on all floors, although only offices are contemplated above the second floor. Further stipulation that the portion of the building on each lot be designed as a unit made provision necessary in the design for the possibility of a future party wall, stairs, elevators, ash hoists, boiler rooms, chimneys and vents. The floor steel

FIG. 3—TYPICAL WELDED FIELD CONNECTIONS, EDISON BUILDING, BOSTON

was arranged to suit these conditions should they arise, and connections for future work were provided.

Design—Inasmuch as the height of the building is over three times its width, wind pressure had to be considered. Special attention was given to details of connections of girders to columns. The load reactions were taken by web angles on the girders, welded to the columns in the field at the toes of the angles. The wind loads were transmitted to the

FIG. 4—WELDED PLATES FOR QUALIFYING WELDERS
The two butt-welded specimens at the left are to be cut into strips 2 in. wide for tension tests. The two fillet-welded specimens at the right are tested in tension to determine the longitudinal shearing strength of the weld

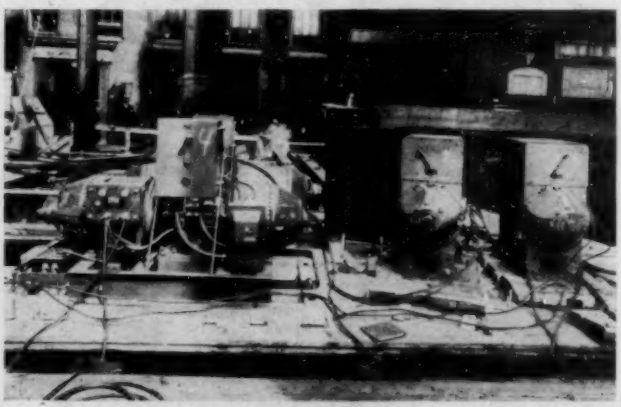

FIG. 5—WELDING-GENERATOR PLANT, BOSTON BUILDING
Four individual-operator machines remained on this platform at rear of first floor throughout all erection work

columns by means of split girder beams on the bottom flanges and plates on the top flanges. For those girders with small moment in the connections, a piece cut from a girder beam with the web riveted to the bottom

flange made vertical field-welding possible to the column on the cut ends of the flange, as shown in Fig 3a.

For the large moment connections (Fig. 3b), split girder beams were used as gussets with the flange riveted to the bottom flange of the main girder. The field-weld was applied where the web contacts the column. Stiffeners along the gusset edge were channels or angles. In the case of some shallow girders, it was necessary to slot the top plate (Fig. 3c) to permit a sufficient amount of fillet weld.

TABLE I—WELDING DATA, EDISON CO. BUILDING, BOSTON

Welding wire used	1,500 lb. of 5/32 in. 1,100 lb. of 3/16 in.
Total	2,600 lb.
Welding wire melted	80 per cent of 2,600 lb., 2,080 lb.*
Electric current consumed	6,120 kw.-hr.
Electrode melted by 1 kw.-hr.	0.34 lb.
Fillet weld (⅜-in., ½-in. and ⅝-in)	60,514 in.
Weld per kw.-hr.	9.9 in.
Weld per lb. of electrode wire bought	23.3 in.
Weld per lb. of electrode melted	29.1 in.
Structural steel	1,314 tons
Structural steel welded	1,050 tons
Weld per ton of steel welded	57.6 in.
Man-hours welding	1,205½
Weld per man per hour	5.02 in.
Welding per man-day of eight hours	Average 33 ft., 6 in.

*Stub ends of electrode wire represent a loss of approximately 20 per cent of wire purchased.

Inasmuch as few fabricating shops are equipped for shop-welding to any great extent and to give all shops a chance to compete, the structural design was made to follow standard practice so far as the shop was concerned, using standard connections (increased to ½ in. thickness to secure a proper ⅜-in. fillet weld) and using customary clearances.

For seat and stiffener connections on columns, regular shop practice was used, except that the seat angle was made wider than the flange of the beam, to allow for field-welding along the bottom flange. Holes for erection bolts were provided to make possible the plumbing, leveling and alignment, without the use of wood shores and braces. Details were so worked out as to eliminate overhead welding.

Erection and Field-Welding—Erection of structural steel was begun on April 9, 1930, with the setting of the cantilever foundation beams and grillages. Welding was begun on April 28, 1930, and completed June 27, 1930. Four welding machines were utilized. The welding crew consisted of a foreman, four welders and an engineer to care for the welding machine, the latter being necessary in order to comply with union requirements. Each welder used the same machine throughout, making it possible to keep accurate records. The field-welding totaled 60,514 in.; 17,780, 16,644, 16,515, 9,575 in. of field-weld made by the welders respectively. Most of the welds were ⅜-in. fillet, although some were ½ or ⅝ in. in size.

The machines were set up in the rear portion of the first floor and

remained unmoved until the welding was completed. The battery of machines is shown in Fig. 5. A voltage of 20 and an amperage of 175 were used except that the amperage was increased to 185 when the upper part of the structure was being welded. The cost of staging was materially reduced by using Z-shaped steel bars of approximately 2 x ½-in. section, which hooked over the tops of the girders and supported a plank on which the welder worked.

Inspection—Local inspection of each weld and qualification tests to determine the competency of welders were important features of the work. At least twice a week each welder was required to run a lap-weld sample which was broken so that the fracture could be examined.

Daily reports were made by the job inspector, giving in detail number of inches of weld for each connection, by whom made and the size of the fillet. Visual inspection only was used.

Qualification of Welders—Before they were allowed to work on the structure all welders were obliged to weld specimen plates for testing. Requirements for each man were as follows: (1) Two lap-welds, one made horizontally and one vertically, to be made and broken when cool to determine amount of penetration, uniformity of weld fracture, etc.; (2) two butt-welds to be made, one run horizontally and one vertically, using two 9 x ½ x 12-in. plates for each specimen, these welds to be machined to the thickness of the plates, the specimens cut into strips 2 in. wide and tested (the highest test specimen of the seven welders who qualified —although only four welders were used on the work—showed 56,500 lb. per square inch ultimate strength, the poorest showed 43,700 lb. and many specimens broke outside the weld); (3) two ⅜-in. fillet-welds 10 in. long, one horizontally and one vertically to be made by welding a 3 x ¾ x 6½-in. plate on each side of plates 12 x 1 in. by 2 ft. 4 in. long, ends separated ½ in. and tested. (The best specimen broke at 155,200 lb. and the poorest at 105,600 lb., giving a value of 15,520 lb. down to 10,560 lb. per linear inch, which represents a factor of safety between 5 and 3½, since the design value used was 3,000 lb. per linear inch). Fig. 4 shows a group of test specimens.

The building was designed by Bigelow, Wadsworth, Hubbard & Smith, architects, Boston. The Whidden-Beekman Engineering Co., Boston, was the designing and supervising engineer for the structural steelwork, floor system and foundations. Frank P. McKibben was consulting engineer on welding and was assisted by William F. Carson, of Carson & Carson, engineers, Philadelphia. The construction work was done by the W. A. & H. A. Root Co., Boston. The American Bridge Co. made the shop details and fabricated the structural steel, F. L. Castleman and H. B Castleman, of that company, giving their personal attention to the welding details. The Daniel Marr & Son Co., of Boston, erected the structural steel, which was field-welded by the Leake & Nelson Co., of Bridgeport, Conn.

Oxyacetylene Welding of Corrosion Resisting Metals and Alloys*

W. B. MILLER†

METALS and alloys are doing major service today in the various chemical and food industries. Welded joints are desirable on account of their neatness and tightness, affording smooth continuous surfaces desirable from the cleaning and insulating standpoints. Very often the plant engineer desires to use a certain metal and prefers welded apparatus. It is the intention of this paper to show that the more common metals and alloys can be oxyacetylene-welded, yielding satisfactory joints. The following table lists some of the more common metals and alloys as well as some of the alloys recently developed to meet certain definite conditions in industry.

Metal	*Use*
Copper	Acetic acid in absence of air
Aluminum	Acetic acid—conc. nitric
Nickel	Acetic acid—sodium hydroxide
Monel	Sea water—sodium hydroxide
Aluminum bronze	Dilute sulphuric acid
Silicon bronzes—Everdur	Cold sulphuric and cold hydrochloric in absence of air
Silicon bronzes—Tempaloy	Cold sulphuric and cold hydrochloric in absence of air
Chromium-iron-alloys	Nitric acid—sea water
Chromium-iron-nickel	Nitric acid—organic acids
Chromium-iron-manganese	Nitric acid—organic acids, etc.
Hastelloy A—Ni-Mo-Fe	Hot or cold hydrochloric, sulphuric or acetic
Hastelloy C—Ni-Mo-Fe	Hot or cold hydrochloric, sulphuric or acetic. Wet chlorine
Hastelloy D—Ni-Si	Sulphuric or hydrochloric.

Let us now consider briefly the welding of the above metals or alloys.

Copper

Copper vessels have been fabricated for some time by brazing or riveting, because of the low strength of welds made in ordinary tough pitch copper. Since the discovery that oxide was the cause of the inferior quality, deoxidized copper is now available for welding purposes, yielding satisfactory welds both as to strength and ductility. On account of the extreme fluidity of molten copper it is necessary to back up the welds. In welding thinner sections it is better to start the welding away from an edge, then finish by welding out to the edge.

Aluminum

The oxyacetylene welding of aluminum is being carried out quite satisfactorily and is almost universally used in the construction of aluminum

*Paper presented at Fall Meeting, A.W.S., Chicago, September, 1930.
†Union Carbide & Carbon Research Laboratories.

apparatus for chemical and food industries. One is referred to the May, 1928, and the January and July, 1929, issues of the JOURNAL OF THE AMERICAN WELDING SOCIETY for articles dealing with the welding of aluminum.

Nickel and Monel

Until it was learned that sulphur caused the embrittlement of nickel, little real success was attained in oxyacetylene welding this metal. Treatment with magnesium renders nickel and Monel malleable and weldable. The welding should be carried out in such a way that the molten metal is not unduly exposed to the air, thus burning out the magnesium with resulting brittleness. Here again it is necessary to weld toward an edge rather than away from it. Backward or backhand welding is also desirable, for it slows the solidification, yielding sound weld metal. It also affords better control of contraction.

Aluminum Bronze

Aluminum bronzes are quite resistive to many corroding reagents. They are difficult to weld due to the formation of an infusible alumina slag. A highly active flux capable of dissolving aluminum oxide at a temperature below the melting point of the alloy is necessary. With aluminum contents up to 8 per cent the welded sheet is quite ductile. With higher aluminum contents eutectoid structures are obtained, the alloys being amenable to heat treatment. This fact should be considered in welding the higher aluminum content alloys if maximum physical properties are desired.

Silicon Bronzes

Everdur and Tempaloy. These alloys are quite resistive to cold acid solutions in the absence of air. They may be welded but to insure best results a thorough knowledge of the physical properties and heat treatment of these alloys is absolutely necessary.

Chromium Alloys

As with all other metals and alloys, success in welding the high chromium alloys is attained only through a thorough knowledge of the properties of the various alloys when subjected to high temperatures such as are met with in oxyacetylene welding practice. Some of the alloys have been unjustly criticized due to a lack of knowledge of the properties of the alloy.

For corrosion resistance other than atmospheric, alloys containing 16-28 per cent chromium are generally used. In oxyacetylene welding any high chromium alloys it is essential that a neutral flame be used, for increase in carbon content removes effective chromium from solid solution. Best results are obtained by applying a suitable flux to the underside of the seam. Without such a procedure it is impossible to obtain good bottom fusion.

Alloys containing 16-18 per cent chromium with low carbon are not so subject to air hardening as those containing 12-14 per cent chromium. They are, however, subject to grain growth, and possibly for this reason, welds and metal adjacent to the weld are considerably reduced in ductility.

Furnace or torch annealing to 650-700 deg. C. followed by air cooling will impart toughness and ductility to welds in this alloy. Oxyacetylene welded tubing after furnace annealing may be cold drawn, flattened or crushed. These tests show the thorough fusion obtained at the bottom of the seam by the use of flux applied to the underside as well as the top and the rod.

The addition of about 2 per cent nickel renders the low carbon 16-20 per cent chromium alloys amenable to heat treatment. On this account these alloys have found considerable use in the manufacture of welded seaplane parts in England. When tempered to 550 deg. C,, these alloys have better corrosion resisting qualities than the cutlery grade of stainless steel. Increasing the nickel to about 8 per cent results in an austenitic alloy or one not subject to the brittleness encountered in the alloys containing no nickel. These alloys with high nickel content do not air harden and weld metal cooled either slowly or rapidly will not become hard and brittle. These alloys are particularly suitable for welded construction since they require no subsequent heat treatment. This statement, however, must be made with reservations, for under certain corrosive conditions, commercial alloys have exhibited selective corrosion adjacent to the weld. It is believed that this condition is due, at least partly, to strain and has been somewhat eliminated by preheating to temperatures ranging from 200-300 deg. C. before welding. Heating austenitic chrome-nickel alloys, 18-8 type, to 500-800 deg. C. has the effect of causing migration of carbon to the grain boundaries and an increased crystal hardness. Reheating to 1000-1200 deg. C. will restore welded material to the best condition for corrosion resistance. The effect on the carbides of heating for long periods up to 800 deg. C. is probably the reason for the production of 18-8 chromium-nickel alloys containing less than 0.10 per cent carbon.

While the 18-8 chrome-nickel alloy is more widely known, alloys containing greater amounts of chromium and nickel are available. They all have high coefficients of expansion, which fact must be considered in welding these alloys. The allowances for contraction will depend on the technique used, it being impossible to lay down any definite rule.

Forged or rolled alloys containing 25-28 per cent chromium with no nickel are used extensively for withstanding oxidation at high temperatures. Weld metal and metal adjacent to the weld will be brittle, but this brittleness is not necessarily an obstacle when it is considered that at a black heat the high heat-affected metal is tough and ductile. Consequently the brittleness is considerably overcome by and during working temperatures.

In May, 1930, before the American Iron and Steel Institute, a new type of chromium alloy suitable for deep drawing was described by Dr. F. M. Becket. It contains approximately 18 per cent chromium with 8-10 per cent manganese, and not over 0.10 per cent carbon together with about 1 per cent copper. These alloys are particularly amenable to hot working, seamless tubing free from seams and other surface imperfections being obtained. In many respects the chrome-iron-manganese alloys are similar to the chrome-nickel alloys. For instance the heat treatment

consists of holding at 1050 deg. C. followed by air cooling. In the polished condition the chromium-iron-manganese alloys are whiter in appearance than other chromium alloys. In regard to corrosion, these steels are resistant to many chemicals as shown by the following table which lists some of the reagents for which they are satisfactory, as well as a few which attack the metal.

Satisfactory	*Unsatisfactory*
10% Acetic c.p. Room Temp.	10% Hydrochloric—Room Temp.
10% Acetic c.p. Boiling	10% Sulphuric—Room Temp.
10% Phosphoric c.p. Boiling	10% Oxalic acid—Boiling
10% Carbolic Boiling	10% Formic acid—Boiling
10% Sodium hydroxide—Boiling	50% Lactic acid—Boiling
Conc. Sulphurous—Room Temp.	85% Lactic acid—Boiling
1% Lactic—64°C.	Bleaching sol.—Room Temp.
2% Lactic—Boiling	16 gr. Cl/liter).
10% Tartaric—Boiling	
10% Chromic (Tech.) Boiling	
10% Malic—Room Temp.	
10% Sodium Bisulfite—Boiling	
10% Sodium Sulfite—Boiling	
10% Ammonium Sulfate—Boiling	
Molten Sulphur—140°C.	
Lemon Juice—Room Temp.	
Canned Rhubarb—100°C.	
Canned Tomatoes—100°C.	
Moist Sulphur Dioxide—600°C.	
Moist Sulphur Dioxide—900°C.	
Moist Hydrogen Sulphide—300°C.	
Sulphite Liquor—Boiling	

It is interesting to note that the chrome-iron-manganese alloys are quite resistant to sulphur bearing gases, in this respect being superior to the corresponding chrome-nickel alloy. This should render them useful for many industrial applications. In oxyacetylene-welding the chromium-iron-manganese alloys, best results are obtained with metal containing not less than 0.3 per cent silicon. Cromaloy flux is used and applied to the under side of the seam the same as for other chromium alloys. The welds have a yield point of about 50,000 lb. per sq. in. and an ultimate strength of about 80,000 lb. per sq. in.

Thus we may say that all chromium alloys may be oxyacetylene welded with the aid of a suitable flux. It allows the use of a neutral flame, blankets the fused metal, and when applied to the under side of a seam, allows thorough welds to be made from one side.

Hastelloys A, C, and D

For some time there has been a need in the chemical industry for an alloy to withstand hydrochloric acid. To meet this need there has been developed a nickel-molybdenum-iron alloy known to the trade as Hastelloy A, which is available in forged, rolled or cast form. It welds easily, the welds showing good resistance to corrosion. The alloy may be joined to steel using Hastelloy A welding rods. On account of the lower melting point of the Hastelloy, it acts similarly to a brazing metal when joined to the higher melting steel. This is a good feature, for long agitator shafts may be built up from a combination of steel and Hastelloy, it being necessary to have only the part in contact with the corrosive agent made of the more expensive molybdenum alloy.

Hastelloy C is also a nickel-molybdenum combination resisting the same reagents as the "A" alloy with the further advantage of resisting dilute nitric acid, wet chlorine, and acid solutions of oxidizing salts. It is furnished in cast form only. In welding it is necessary to preheat to avoid cracking.

Hastelloy D is a cheaper alloy than A or C and consists of nickel with approximately 10 per cent silicon, 1.5-2 per cent aluminum and 3 per cent copper, and is obtainable only in the form of castings. The alloy is machined with difficulty with tungsten carbide tools. These tools may be used for facing off a flange when grinding is not convenient. This alloy presents quite a difficult problem due to the formation of an alumina-silica refractory slag. The metal has a low melting point and is weak just after solidification; hence it requires careful preheating and cooling to avoid cracking.

In this brief outline we have attempted to show that the many corrosion resistant alloys available may be welded by the oxyacetylene welding process. Each alloy has distinctive physical properties which must be considered before any apparatus is welded for service.

In conclusion the writer wishes to express his indebtedness to Mr. Russell Franks for the data on the chromium-iron-manganese alloys.

Cold Facts Concerning the Welding of Battered Rail Ends*

S. E. TRACY†

EVERY railroad in the world is of necessity deeply interested in the processes of building up battered rail ends in order to effect a solution of one of the most serious problems of operation. It is an accepted fact that the battered rail end is either the direct or indirect cause of a large part of the trouble and expense incident to the maintenance of the track structure.

In the minds of railroad engineers, there is no question as to the effectiveness and economy of the procedure of building up battered rail ends, in order to improve the riding qualities of the track; to increase the life of rail in first position; to decrease the wear upon track fastenings and to minimize the wear and tear on equipment. There is, however, some difference of opinion as to what method of building up rail is most effective and economical.

From time to time articles have been published in the railroad journals and papers have been read before meetings of welding societies and railroad associations in which the subject of battered rail end weld-

*Read before the 31st Annual Convention, International Acetylene Association, Chicago, Ill., Nov. 12, 13, 14, 1930.

ing has been discussed. In many cases the statements and data contained in these papers have not been supported by the complete and accurate data which is necessary for proper analysis or as a basis for the formation of accurate conclusions. In many instances these articles have contained broad and unsupported statements as to the physical characteristics of the weld metal applied and inadequately supported cost data as to the expense involved in completing the operation. Some of this information is not in agreement with results reported by accredited investigators nor does it conform with the conclusions reached by means of carefully conducted tests.

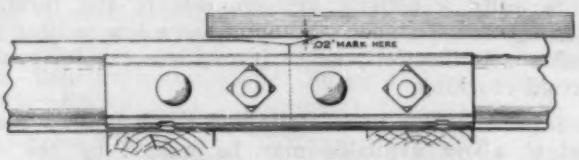

FIG. 1 METHOD OF MARKING HIGH RAIL

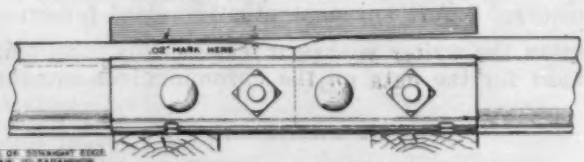

FIG. 2 METHOD OF MARKING LOW RAIL

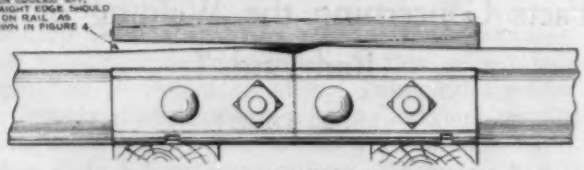

FIG. 3 FINISHED WELDED JOINT - HOT

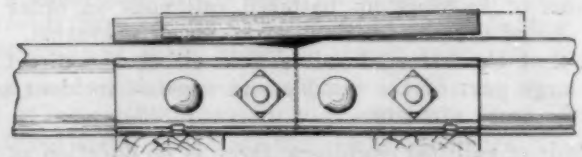

FIG. 4 FINISHED WELDED JOINT - COLD

The question is not whether or not rail ends should be built up but rather what process of performing the operation insures the best results as to quality, duration of extended life, and cost.

The two fusion welding processes which have reached the highest stage of development, the oxy-acetylene torch and the electric arc, are both in use by all of the principal railroads and have proven effective in promoting economy and efficiency in the maintenance or railroad facilities. The important problem in connection with their application is to determine definitely and accurately the limits of the field to which each process should be applied.

On many classes of work there is a rather wide spread between the hourly cost of operation as between the oxy-acetylene torch and the electric arc, the differential being in favor of the arc. In the absence of complete analysis of costs and results, the fact that the arc cost per hour is lower than the torch cost per hour, has led to many errors in the application of the two processes with the result that the full economy promised by fusion welding has not been realized. This appears to be particularly true with regard to track work, and it is the object of this paper to present such facts and data as have been developed, so that a definite conclusion may be drawn as to the comparative merits of the two processes for use in the building up of battered rail ends, which is one of, if not the most important operation to which fusion welding has been applied on the railroads.

FIG. 5 - LOW OR BENT JOINT

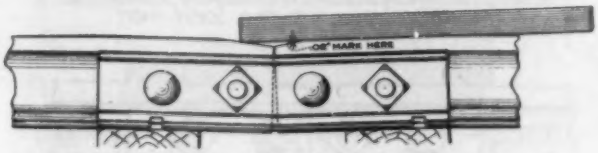

FIG. 6 METHOD OF MARKING R.H. RAIL

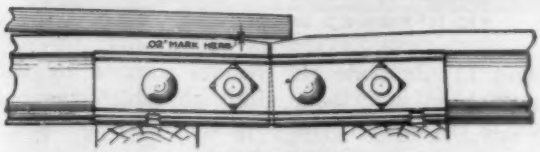

FIG. 7 METHOD OF MARKING L.H. RAIL

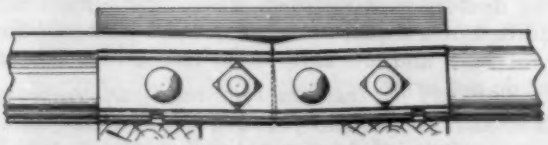

FIG 8 FINISHED WELDED JOINT - COLD

The electric arc is comparatively a newcomer in the field of rail end welding and was taken up by some with the laudable desire to further reduce the cost of welding and thereby increase the economies secured. Both processes have now been in use for a number of years and accumulated data make it possible to arrive at definite conclusions as to which method of procedure promises the greatest ultimate economy.

A brief study of the condition which rail end welding is designed to correct is necessary in order that the results secured by the two processes may be fairly compared. It should be understood that welding is

not a cure for low joints or for surface bent rail. The welding procedure corrects the batter but low joints must be raised by the usual process of tamping up the ties.

Figure 9 illustrates a condition wherein perfectly matched rail, which has not been surface bent or pounded low in surface, is merely battered at the ends. This condition, is obviously, not difficult to correct by the welding process.

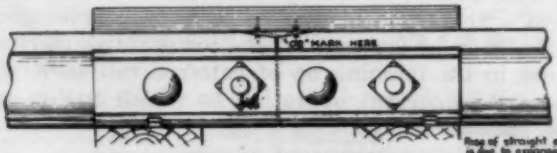

FIG 9 METHOD OF MARKING

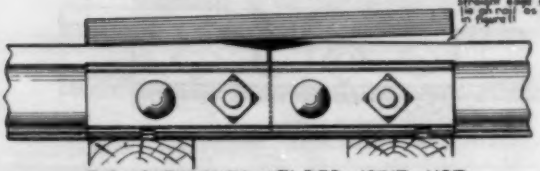

FIG 10 FINISHED WELDED JOINT - HOT

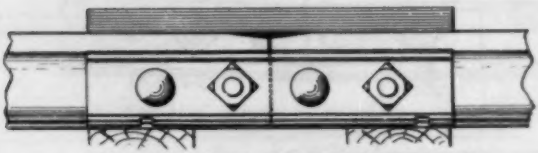

FIG 11 - FINISHED WELDED JOINT - COLD

Figures 10 and 11 illustrate the results secured by welding joints such as have just been described. Rail on which the only defect is simple end batter is not often found on track which is ready for welding.

In Figs. 12, 13 and 14 is illustrated the condition of unequal batter usually found on double track railroad, where traffic movement is all one way. This condition of unequal batter may exist in connection with bent, out of surface, or high and low rail, or, as in the case illustrated, where those conditions do not exist.

Another rail condition frequently found is where adjoining rails are mismatched. One rail being higher than the other. When a straight edge is laid across this type of joint with one end held down on the lower rail and the center resting on the end of the high rail, space will be seen between the straight edge and the rail extending from the end of the straight edge on the low rail to the end of batter on the high rail and also from the end of batter on the high rail to the end of the straight edge. This condition is illustrated in Fig. 2.

The appearance of such a joint when a straight edge is placed upon the high rail is illustrated in Fig. 1, which shows not only the depression at the end of both rails, due to batter, but also the inequality in rail surface due to unequal thickness of the rail.

The purpose of the welding operation is to remove the batter and to match up the rail ends as evenly as possible so as to permit the smooth transfer of wheel loads from one rail to the other without the objectionable impact. It is clearly out of the question, in the case of high and low rails, to carry out the welding operation to the point where an absolutely level rail surface is secured and the best results, both in economy and in improvement of track riding qualities, are secured by the methods here illustrated.

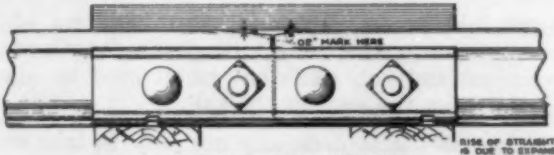

FIG 12 METHOD OF MARKING

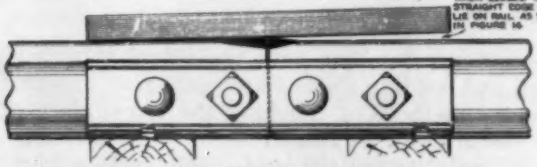

FIG 13 FINISHED WELDED JOINT - HOT

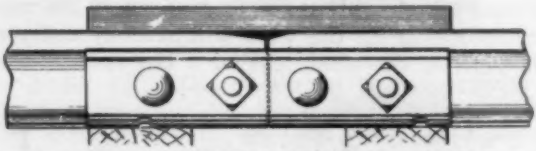

FIG 14 FINISHED WELDED JOINT - COLD

The method of welding where high and low rails join is illustrated in Figs. 3 and 4. In this case it will be seen that the object is to completely fill up the batter and to build a short runoff on the low rail so as to eliminate the hammer blow which occurs when a wheel moving over the low rail hits the end of the high rail, or moving over the high rail drops on to the end of the low rail.

Our experience has been that at least 90 per cent of the rail which is ready for welding has developed either a slight bend or has been hammered low in surface at the joint. In applying a straight edge to joints in this condition, we find that there is a space between the straight edge and the rail varying in length from a few inches to the full length of a 24 in. straight edge. In order to restore the track to good running surface it is not necessary to fill in the entire space between the straight edge and the rail, nor is any good accomplished by so doing. This fact, which is proven by long experience, should be remembered in future consideration of the application of the two processes.

The condition described above is illustrated in Fig. 5.

The proper use of the straight edge, in marking bent or low joints for welding, is illustrated in Figs. 6 and 7 and the appearance of the

completed weld on this type of joint is shown in Fig. 8. In this case it will be noted that the batter has been corrected but that a slight depression, greatly exaggerated in the illustration, still exists at the joint due to the bent condition of the rail, or low surface of joint.

It is not necessary to level up the surface of the joint by carrying the weld back beyond the batter and if this is attempted the cost of the weld will be excessive with no compensating improvement in the riding qualities of the track or in the increased life of the rail.

In the oxy-acetylene process, by proper manipulation of the straight edge and the use of a taper gauge, the maximum length of the weld required is determined and only sufficient metal need be applied to take out batter and match up the ends of the rail.

In the electric process it is necessary not only to take out the batter but to apply sufficient additional metal to correct the low space between the straight edge and rail.

To those not entirely familiar with the actual application of the two processes in rail end welding these statements may appear unreasonable. However, when the methods of finishing the top surface of the rail are considered the reasons can be readily seen. The necessity for applying an excess of weld metal to the arc welded joint arises from the fact that these welds must be ground to finish, and unless sufficient metal is applied to compensate for the difference in contour of the rail at the joint the grinder in smoothing up the weld will actually cut metal from the ball of the rail, back of the weld, leaving a low spot at each end of the weld.

On a test section of track built up by the electric arc process we found it necessary to weld 40 per cent more surface of the rail than would have been necessary with the oxy-acetylene process to obtain the same object (we hesitate to say "the same result"). On this stretch of rail it was necessary to deposit with the electric arc process 0.75 lb. of metal per joint while on adjacent track welded by the oxy-acetylene process only 0.0679 lb. per joint were required.

The conventional grinder used in the finishing of rail ends, on both the surface and the sides, consists, briefly, of a grinding wheel mounted on a four wheeled car. The grinding wheel is located in the approximate center between the running wheels. The running wheels are guided during the grinding operation by the rails at a distance of from one to three feet from the weld. The rails at this distance are out of surface by some hundredths of an inch with the rail at the position of the weld. This necessitates the raising and lowering of the grinding wheel to compensate for any differences in the contour of the rail head. As already explained, unless sufficient metal has been applied and left on the rail to compensate for the difference in contour, the grinder will dig into the ball of the rail at the end of the weld.

The procedure with the oxy-acetylene torch involves the forging of the deposited metal with a hand hammer as the weld progresses. In addition the weld is completely reheated and smoothed by forging with a flatter

and sledge. During the process, any mushroomed or overhanging metal on the rail is brought to forging heat and hammered back into place, thereby lessening the amount of weld metal required and improving the quality of the weld by working out any seams or impurities which may exist in the rail end.

The expansion between the rails is restored after the welding operation is completed by the use of a hot cut chisel and sledge. The rail ends are heated up to the required temperature and the overhanging ends of the rail are cut off, the top edges being bucked back by the wedging action of the chisel. No grinding is necessary with the oxy-acetylene process.

In the application of the electric arc process in rail end welding it is obviously impossible to forge the deposited metal; the rod deposited chills immediately to an extent which makes beneficial hammering impossible. Neither is it possible to heat up the overflow metal which, in this case, must be ground off and is lost. Any imperfections in the metal of the rail cannot be removed with the arc but remain in the finished joint. The expansion between rails must also be ground in order to remove the overhang and prevent rapid chipping of the rail.

The quality of the weld metal applied in bulding up rail ends is of paramount importance, as the section of the rail to which the weld is applied is subjected to greater stress than any other part of the rail. For this reason it is necessary that the welded rail end be harder than the original rail metal and at the same time it must not be so brittle that it will check or break out. The reason for the superiority of the metal deposited with the oxy-acetylene flame over that deposited with the electric arc will be readily seen when the methods of application are considered.

The physical characteristics of the metal deposited on rail ends is a matter of the greatest importance. While a degree of hardness somewhat above that of the rail metal is desirable, this characteristic alone does not insure the desired results. High carbon steel, which will give the required hardness, has proven unsatisfactory because of lack of ductility or toughness. While the rail ends are sufficiently hard they are subject to checking, cracking and to flaking out or chipping.

Certain alloys containing chromium have proven the most suitable for the building up of rail ends, for the reason that they provide the required hardness and in addition make welds sufficiently tough to prevent breakage under the hammer of the wheels. These low chromium alloy rods, when properly applied, which entails forging during the procedure of welding but no subsequent heat treatment, produce a weld of approximately 320 Brinell. The average hardness of standard carbon steel rail, from tests recently conducted, is 267 Brinell.

The relative hardness secured in metal deposited by the two processes is shown in figures published by the American Railway Engineering Association, in its proceedings for 1929. A subcommittee of this body made a complete investigation of the characteristics of electric arc and oxy-acetylene rail end welds and their report covering hardness tests

is quoted below. Information is not at hand as to the kind of rod used in making these welds but, from the readings, it can be assumed that the filler used for the oxy-acetylene process was not chromium alloy, which would have given even higher values than those quoted.

EXHIBIT "A"

HARDNESS TEST ON OXY-ACETYLENE WELDED RAIL ENDS

Specimen No.	Rail Section	Hardness on Top of Head								Hardness on Side of Head				
		½"	1"	2"	3"	4"	5"	6"	7"	½"	1"	2"	3"	4"
1	90 lb. ARA	279	...	250	...	292	...	...	295	243	250	...	...	243
2	90 lb. ARA	232	250	250	263	...	...	276	...	243	256	219	...	...
3	90 lb. CS	250	226	244	238	278	290	...	...	224	225	219	225	263
4	90 lb. CS	270	273	277	256	237	263	...	250	244	257	250	257	216
5	100 lb. RE	264	257	280	264	...	250	...	...	250	274	272	250	264
6	90 lb. ARA	265	250	250	243	236	...	257	...	221	...	228	250	257
7	100 lb. RE	256	256	262	250	277	276	...	...	250	...	244	...	250
8	100 lb. RE	263	263	269	262	250	...	...	...	271	270	250	...	255
9	90 lb. ARA	250	250	250	250	238	250	...	267	224	230	250	250	...
Average		259	253	259	253	244	266	266	271	241	252	242	246	249

NOTE: The inches shown on statement represent distance from end of rail.

EXHIBIT "B"

HARDNESS TEST ON ELECTRIC WELDED RAIL ENDS

Specimen No.	Rail Section	Hardness on Top of Head								Hardness on Side of Head				
		½"	1"	2"	3"	4"	5"	6"	7"	½"	1"	2"	3"	4"
1-A	90 lb. ARA	217	230	238	238	246	232	...	...	253	262	...	...	...
2-A	90 lb. ARA	235	244	236	236	236	244	...	252	237	230	...	...	...
3-A	90 lb. ARA	232	248	237	244	254	262	262	...	...	...	262	243	262	262
3-B	90 lb. ARA	230	217	236	246	231	234	...	262	243	244	244	245	...
Average		229	235	237	241	242	243	262	257	244	250	243	253	262

NOTE: The inches shown in statement represent the distance of readings from end of rail.

It will be seen from these figures that the oxy-acetylene welds were considerably harder than the electric welds and would obviously give longer wear. When further consideration is given to the superior toughness of the acetylene weld the comparison becomes markedly in favor of that process.

The savings secured by the railroads through the reconditioning of rail ends depend mainly upon the quality of the work. The built up joints must permit the rail to remain in position a sufficient length of time beyond its ordinary life to more than cover the charges entailed by changing out the rail. The added life which it is necessary to gain in order to secure economy will, of course, depend upon traffic conditions and standards of maintenance and cannot be expressed as any number of years to cover all conditions but rather as a percentage of the ordinary life of the rail.

The economies resulting from rail end welding, under proper procedure, are very large, but this does not lessen the desirability of selecting

the method which promises the lowest initial costs consistent with the required quality.

On the test section of track, previously mentioned, accurate account was kept of all costs entering into the welding of the battered ends. The overall cost per joint by the electric arc process was $2.0144, while similar joints on adjacent track were welded by the oxy-acetylene process at an overall cost of 81c.

It should be understood that the equipment with which this test job of electric welding was done was not of the most up to date design for this type of work and we know that the cost could be materially reduced below the figure given.

After a thorough investigation of the most approved apparatus available for electric rail end welding, and an analysis of the results secured by other railroads, we have figured that the absolute minimum cost per joint which we could hope to secure by the electric arc process on joints such as were welded in this test would be $1.17. The basis for this calculation is given in the following detailed figures:

COST OF ELECTRIC WELDING JOINTS UNDER MOST EFFICIENT OPERATING CONDITIONS

Item	Cost per Joint
Labor	$0.6728
Gasoline and oil	.0350
Electrodes	.1225
Interest, depreciation and repairs on equipment	.1655
Grinding wheels	.1106
Miscellaneous tool charge	.0500
Supervision	.0180
	$1.1744

NOTE: Based on 40 joints per eight hour day, per unit.

COST OF WELDING RAIL END BY OXY-ACETYLENE PROCESS

Item	Cost per Joint
Labor	$0.353
Gases and equipment charges	.369
Rod	.020
Miscellaneous tool charge	.050
Supervision	.018
	$0.810

NOTE: The above costs do not include freight charges on materials or equipment in either case.

A most important point to be considered in comparing the two processes is that of the investment required in order to carry out the yearly program of rail end welding. In order to build up 200,000 joints yearly, which is our approximate average, seventeen (17) complete outfits of electrical equipment and apparatus, representing an investment of $107,610.00, would be required. To accomplish the same work by the oxy-acetylene process, under service contract, thirty (30) complete sets of equipment, representing an investment of $2,570.10, are required. The welding and cutting torches, oxygen and acetylene regulators, track trucks and miscellaneous equipment are furnished to the railroad under

service contract and the carrying charges thereon are included in the cost of gases.

The following figues show in detail the investment necessary in electric arc and oxy-acetylene equipment to carry out a yearly program of 200,000 joints:

OXY-ACETYLENE PROCESS

One Unit

Acetylene and oxygen hose and fittings	$38.50
Hotcut, flatter, sledge, cold chisel, hammer	5.50
Straight edge, goggles, windshield	7.52
Welding and cutting tips and wrenches, lighter, etc.	19.15
Miscellaneous other small tools and equipment	15.00
	$85.67
30 sets required—total investment	$2,570.10

NOTE: The above is based on 22.6 joints per eight-hour day, per welder.

ELECTRIC ARC EQUIPMENT

One Unit

Gas engine, generator outfit	$3,500.00
Rail surface grinder	800.00
Rail end grinder	102.00
Transformers	150.00
Remodeling car for generator equipment	500.00
Cable and fittings to cover ½ mile	1,188.00
Miscellaneous equipment, tools, etc.	90.00
	$6,330.00
17 sets required—total investment	$107,610.00

NOTE: The above is based on 40 joints per eight-hour day, per welder.

Since 1922 we have welded approximately 1,092,000 rail joints with a steadily decreasing cost from an average of $1.32 a joint in the first years to 76.7c. for this year up to September 1. The reduction in cost is due to several factors, such as reduced price of gases, increased efficiency of welders, improvement in the procedure of welding the joints, and some variation in the general condition of the rail ends welded.

In building up a stretch of track, the accepted standard of minimum batter is 3/100ths of an inch. When rail is welded as soon as batter of this kind has developed the maximum economies result as in this case the rail end condition is corrected before serious damage has been done to the angle bars and before the riding qualities of the track have been seriously impaired. Joints of this type can be restored by the oxy-acetylene process through the application of a few ounces of metal. while with the electric arc process it is necessary to deposit from one-half pound upward in order to secure the stock required for the subsequent grinding operation.

Some have perhaps been deceived by the good appearance of the ground joint immediately after completion, and have not made sufficiently thorough investigations of hardened surface as related to the rail as a whole, or of the wearing qualities of the weld metal to enable them to reach reliable conclusions as to comparative ultimate results secured through the application of the two processes.

Classification and Physical Tests for Various Types of Welded Plate Joints

By G. R. EXLEY†

IN the study of weld-fabricated joints, it should be borne in mind that the base and weld metals are strained simultaneously and rupture may occur in either, depending entirely upon the composite qualities of the physical properties of the specimen as a whole. The results obtained from "slow" or "equivalent static" tensile tests for a series of similar specimens are comparable when the assembled parts of the unwelded specimens conform to a definite size, shape, and gauge length. The extra material required to make the joint is disregarded in this respect.

The physical properties or "variables" can be measured by the degree suitable for obtaining individual properties of either the weld or base metal, tested under the same conditions. Fabricated specimens are not suitable for obtaining individual properties of either the weld or base metal. When such results are desired the specimen should be made entirely of the metal under consideration.

When the specimen is built up for any given case it may be regarded as a working specimen, and a general classification of the results should be made with due regard to the limitations of the conditions under which the test was made. Any variation in the quality, size, or disposition of any one of the different elements will greatly influence the results for the others.

It is generally known that direct stresses are more evenly distributed and transmitted by members having uniform symmetrical sections than by those with abrupt or unsymmetrical changes. It is easily understood that unsymmetrical changes in section will induce complex moment stresses in addition to the direct stress; and an abrupt change will complicate the flow of the metal, there being a restriction at the greater mass, while the work of rupture will be confined to the minimum section, and high local stresses will develop at sharp corners and re-entrant angles, the effect of which will be felt most in a brittle or non-extensible metal.

From the preceding remarks it is not difficult to define the variables upon which a classification of the various types of welded joints can be based. Briefly stated, these are as follows:

(*a*). A uniform section.
(*b*). An abrupt symmetrical change in section.
(*c*). An abrupt eccentric change in section.
(*d*). Like metals.
(*e*). Unlike metals.

The term "like metals" refers to an ideal duplication in the weld metal of all the strength properties, elastic constants, and ductility possessed by

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the base metal. To produce a weld metal essentially the same as the base metal would require full control of the metallurgical chemical, and technological processes applicable to the "variables" involved, namely:

(*f*). Ultimate strength.
(*g*). Elastic limit.
(*h*). Yield point.
(*i*). Energy of rupture.
(*j*). Ductility.
(*k*). Endurance limit.
(*l*). Direct modulus of elasticity.
(*m*). Transverse modulus of elasticity.
(*n*). Physical structure.

The stress-resisting qualities of these properties may be stated as:

(*o*). Strength.
(*p*). Resilience.
(*q*). Adaptability to overstrain.
(*r*). Impact resistance.
(*s*). Fatigue resistance.
(*t*). Volumetric elastic deformation.
(*u*). Effective stress distribution.

Disregarding the unlimited range of these variables for all kinds and grades of metals, this article will be confined to mild steel and a suitable grade of welding wire. The properties to be found in a deposit of mild steel weld metal as compared with those for a similar grade of rolled steel may be stated as follows:

(*v*). The ultimate strength, elastic limit, direct and transverse modulus of elasticity are quite normal.

(*w*). Tests for ductility and elongation indicate irregularities in these properties.

(*x*). In regard to the endurance limit as a measure of fatigue resistance, the information at hand does not warrant a statement at this time.

(*y*). The physical structure of weld metal is a much discussed topic and rightly deserves such consideration, as this is probably the most erratic variable of the entire group. Structural investigations should include all physical irregularities such as flaws, shape, and inclusions as well as the natural crystalline formation. Structural faults are usually referred to as contributions from poor equipment, bad manipulation, inferior materials, lack of supervision, incorrect designs, inexperienced welders, and even the disposition and personality of the welder.

Aside from what has been said, good weld structures can be, and are being produced on a large scale by both hand and automatic processes, and whatever difficulties exist from these sources will eventually be corrected by proper materials, equipment, supervision, inspection, and process procedure control.

Referring to the classification variables (*a*), (*b*), (*c*), (*d*) and (*e*) for various types of joints it is easily seen that a uniform section (*a*) and like metals (*d*) would produce a perfect joint, although a uniform section

and unlike metals would be inefficient as regards the affected variables of the weld metal. An abrupt symmetrical change in section (*b*) and like metals (*d*) would be inefficient as regards volumetric elastic deformation essential to proper stress distribution.

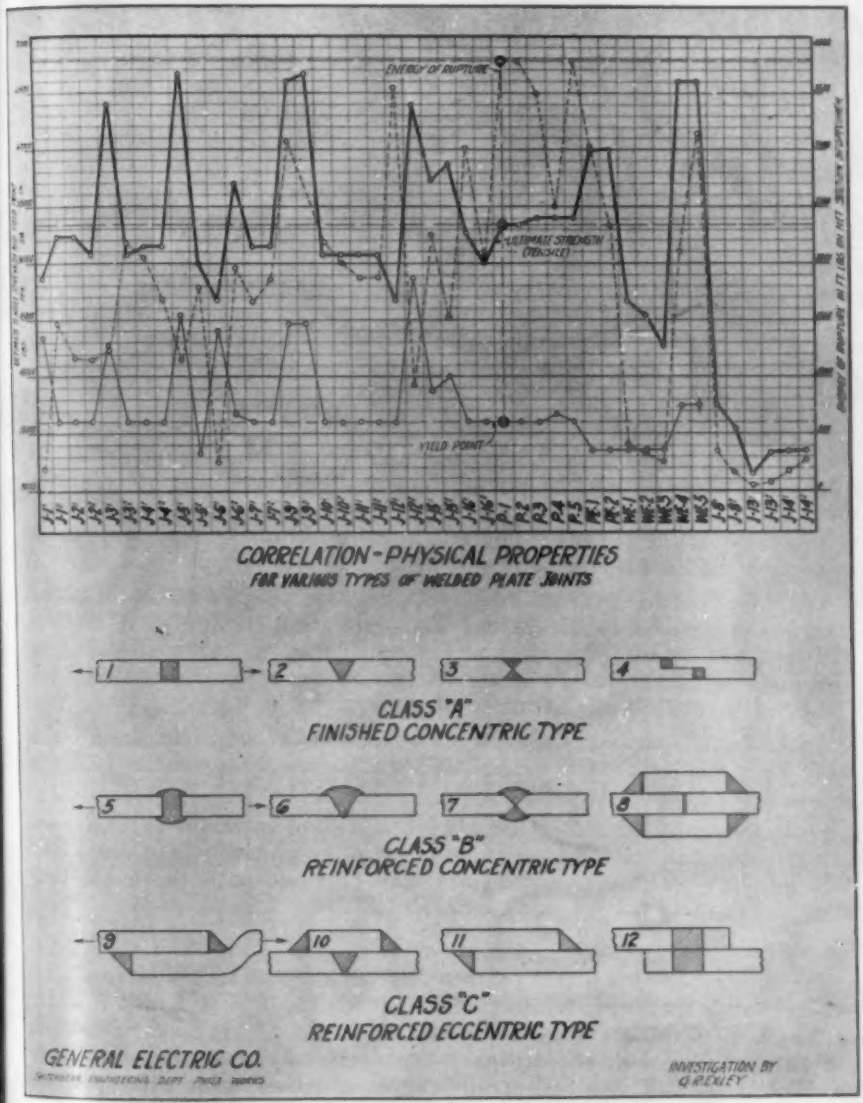

FIG. 1—PHYSICAL PROPERTIES OF VARIOUS WELDED JOINTS

Joints *J*-1 to *J*-6 embody an abrupt eccentric change in section.
Joints *J*-7 to *J*-12 embody an abrupt symmetrical change in section.
Joints *J*-13 to *J*-16 are special types of joints.
Specimens *P*-1 to *P*-5 are plain plate sections.
Specimens *PE*-1 and *PE*-2 are plain plate sections of special eccentric type.
Specimens *WE*-1 to *WE*-5 are welded joints of special eccentric type.

With an abrupt eccentric change in section (*c*) the conditions for the previous case would exist with further complications from complex moment stresses due to the eccentricity.

The next point for consideration is a practical one, and may be regarded as a logical compromise between theoretical and practical deductions. Theoretically, the perfect joint would consist of like metals and a uniform section, i.e., the weld would have to be finished flush with the plate surfaces. A practical joint for economical reasons would be as deposited, unfinished, and would extend outside the plate surfaces, to insure a full thickness of joint. The weld metal as regards some of the variables would be unlike the base metal. Here it will be well to mention the lack of ductile extensibility, and the structural irregularities of ordinary weld metal which primarily possesses the characteristics of cast metal.

Ductile extensibility has to do with the energy of rupture, a measure of resistance to impact and adaptability to overstrain, the latter being associated mostly with the incidental bending stresses induced by eccentric connections, scant welds, or accidental irregularities such as flaws or inclusions in the weld structure.

Taking into account the irregularities mentioned it is to be observed that the naturally deposited or unfinished weld, when made symmetrical and somewhat thicker than the plates joined, affords a means of reinforcement against failure in this manner. The practical joint would therefore consist of the variables (*b*) and (*c*), an abrupt symmetrical change in section, and unlike metals.

The effect of this type of joint is to increase the resistance to lateral contraction parallel to the joint. The weld metal acting as a strut or stiffener will be subject to the stress considerations for such members. The plates adjacent to the weld will receive an unequal distribution of stress with subsequent abnormal effects.

Aside from considerations of strength, the added weld metal of a reinforced weld will provide against porous leaks, an essential factor in pressure vessel construction.

For purposes of identification, the classification variables (*a*), (*b*), and (*c*) are shown in the lower section of Fig. 1, respectively, as classes "*A*," "*B*," and "*C*." Other classifications may be made with the metal variables (*d*), and (*e*).

Specimens

The type of specimen selected for this work is not an all-purpose type, but rather a very specific one. The gauge length and width conform to the A. S. T. M. standard for plates and flats. This specimen should not be confused with the ordinary type generally used for shear tests on fillet welds. The stress-strain curves obtained with this specimen are of particular advantage as a measure of ductility.

Reference Symbols

The markings for the various specimens are as follows:

J—Indicates a welded joint.

P—Indicates a plain plate.
PE—Indicates a plain plate—special eccentric type.
WE—Indicates a welded joint—special eccentric type.

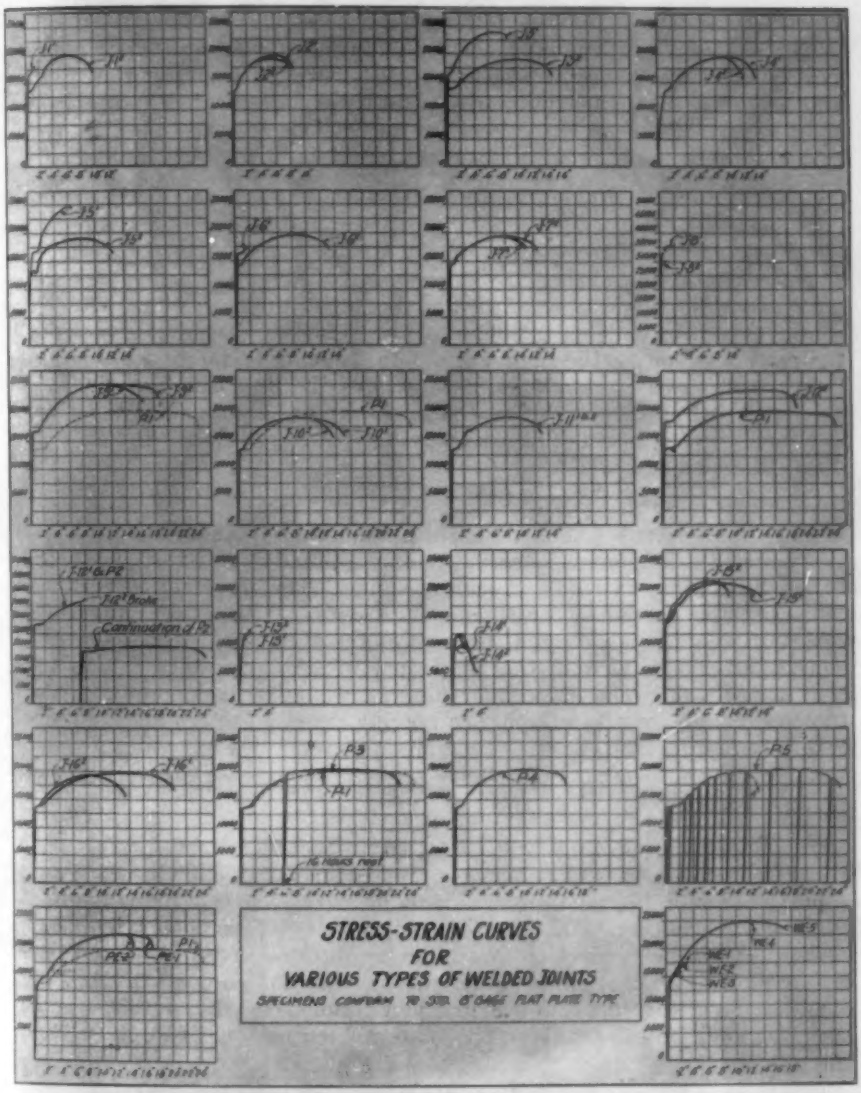

FIG. 2—STRESS-STRAIN CURVES FOR VARIOUS WELDED JOINTS

Joints *J*-1 to *J*-6 embody an abrupt eccentric change in section.
Joints *J*-7 to *J*-12 embody an abrupt symmetrical change in section.
Joints *J*-13 to *J*-16 are special types of joints.
Specimens *P*-1 to *P*-5 are plain plate sections.
Specimens *PE*-1 and *PE*-2 are plain plate sections of special eccentric type.
Specimens *WE*-1 to *WE*-5 are welded joints of special eccentric type.

The *J* specimens were made in pairs, the individual specimens being indicated by the small numeral exponents (1 and 2) written with the joint number given under the photographic reproductions of each of the specimens.

Material

The material used for all *J* and *P* specimens was an ordinary grade of tank plate. The physical properties are shown by Curve *P*-1 in Fig. 2 and are given for comparison in several cases as indicated by the dotted lines superimposed on the curves of the various joints. Specimens *PE* and *WE* were made from structural steel flats. All specimens were ¼ in. thick except *J*-8, which was ¾ in. An ordinary grade of welding wire was used in all cases.

Diagrams and Photographs

The stress-strain curves are shown in Fig. 2. The vertical or stress scale gives the *actual load* on the net section of the specimen. The horizontal or strain scale is in inches. Fig. 1 shows the correlation of all the calculated properties. In Figs. 3 to 8 inclusive the specimens have been arranged in pairs, one on each side of the line sketch of the joint. Two views of specimens *J*-1 to *J*-12 inclusive are shown. For the others only one view is given. The markers at the edge of the specimens indicate the elongation.

General Remarks

In addition to the accompanying diagrams and photographic reproductions of all the specimens, observations were noted during test and a careful post-examination made of each specimen. The information was then tabulated and examined for fundamental data. It was first intended to report these data as collected for each of the specimens. On second consideration, and in view of the recurrence of similar results, it appeared that a more comprehensive understanding would be had from a general treatment with proper reference to specific cases. The results are therefore reported in the following general summary.

SUMMARY OF TENSILE TEST RESULTS

Variable (a): A Uniform Section

Two specimens of this type (*J*-12 and *J*-16) were tested. Specimen *J*-12[1] was machined slightly below the surface of the plates to insure rupture in the weld. The test was made in parallel with a plain specimen *P*-2 inserted at the same time for comparison. With only a few thousandths of an inch reduction in section, rupture occurred at a little over 0.7 in. elongation. Specimen *J*-12[2] was machined a comparative amount oversize, resulting in about 1.8 in. elongation. The slight difference in size was sufficient to transfer the concentrated energy of rupture from the weld to the adjacent plate.

Specimen *J*-16[1] was finished exactly flush with the plate surfaces. The results obtained for this specimen were more nearly normal compared with a plain plate than for any other type tested. The results in terms of efficiency as compared with *P*-1 are given below:

Ultimate strength	99 per cent
Yield point	100 per cent
Energy of rupture	81 per cent

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From these results it would seem that good evidence of the effects of the variable (*a*) is to be found in this specimen. Specimen *J*-16' was not finished exactly flush with the plates, the welds being slightly reinforced. The result was a lower energy of rupture.

Variable (*b*): *An Abrupt Symmetrical Change in Section*

Five specimens of this type (*J*-7, 8, 9, 10, and 11) were tested. All

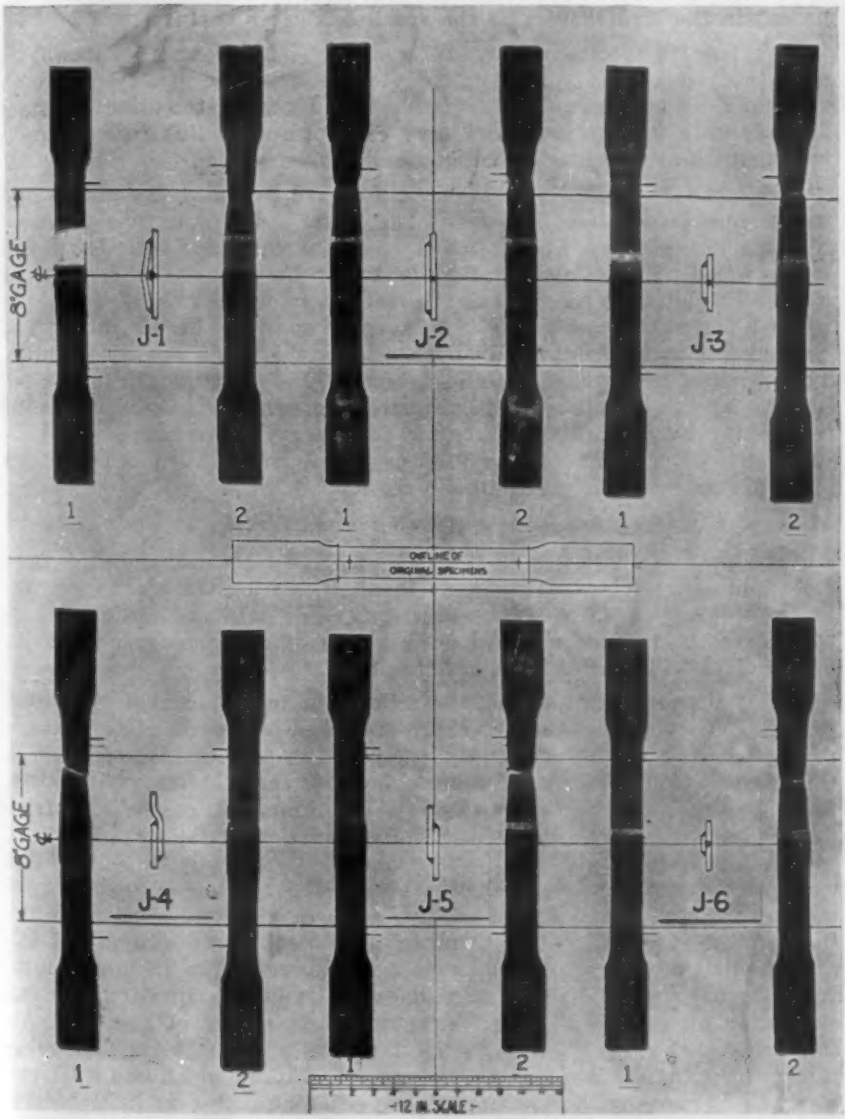

FIG. 3—JOINTS HAVING AN ABRUPT ECCENTRIC CHANGE IN SECTION (FRONT VIEW)

broke in the plates except *J*-8, which was intended to break at the welds, the plate in this case being ¾ in. thick. (Specimen *J*-10 has the appearance of an unsymmetrical section. A number of tests with this type of specimen warrant the classification it has been given here when proper reinforcement and good penetration are assured.) The fact that all of the ¼-in. specimens broke in the plates would seem to be evidence of the reliability secured by the equal stress distribution in the welds when the section is symmetrical. The absence of bending is also apparent in the straightness of the specimens after rupture.

Referring to specimens *J*-7, -10, and -11 (Figs. 5 and 6), it will be seen that elongation was restricted to the ruptured plate while both sides of *J*-9 were elongated. This shows a better distribution of stress and accounts for the greater energy of rupture for this pair of specimens, which are obviously the outstanding members in this class.

Specimens *J*-7 and *J*-8 were made for comparison. The straps and welds were made alike; but *J*-7, made from ¼-in. plate, was intended to break in the plate. Specimen *J*-8 was ¾-in. thick and intended to fail in the welds. The purpose was to determine the factors for both conditions. The ultimate strength of the plate was found to be 51,400 lb. per sq. in. The welds were good for an average of 34,000 lb. per joint. The thickness of plate that could be developed by the welds would be 0.66 in. The ultimate strength of a plain specimen (*P*-1) was 53,400 lb. per sq. in. Using this as a basis, the ultimate strength efficiency would be 96 per cent. From similar reasoning the energy of rupture would be reduced to 47 per cent. These differences may be regarded as the effects of an abrupt symmetrical change in section.

Variable (c): An Abrupt Eccentric Change in Section

Nine types of this class (*J*-1, -2, -3, -4, -5, -6, -13, -14, and -15) were tested, making eighteen specimens in all. Nine of the eighteen broke in the welds. There is no doubt that bending was not the chief contributor to these failures. An examination of the photographs (Figs. 3, 4, and 7) will bear out this statement.

Out of the nine pairs tested, the failures of five alternated from weld to plate. That is, one occurred in the weld and one in the plate for each pair. This is probably due to the excessive bending stresses present in this type of joint, and would seem to indicate that the margin of resistance in either case is rather small. An examination of the weld fractures gave further evidence of the slight variation in the weld structure required to cause failure in this manner. Referring to *J*-1', as an example, the fractured weld showed an eight per cent reinforcement on the strap side of the "V" weld and a five per cent lack of penetration for the opposite side. With this scant reinforcement and the breach at the extreme tension fibers the conditions were favorable for a rapid failure. As indicated in the stress-strain diagram, failure occurred within an elongation of about 0.2 in., giving a very low energy of rupture. An examination of *J*-1', which failed in the plate, showed 20 per cent reinforcement with only two per cent lack of penetration, which was sufficient to transfer most of the bending to the adjacent plates as indicated by the bends at these points.

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Specimen *J*-3' gave a similar result to that for *J*-1'. In this case failure was due to an inclusion (at left-hand side of fracture shown in Fig. 3) which again gives evidence of the small margin of safety in resisting the excessive bending stresses in this type of specimen.

As a check on the variable (*c*), specimen *P*-4 was made for comparison with *J*-3'. The same size strap was welded to a plain specimen to observe

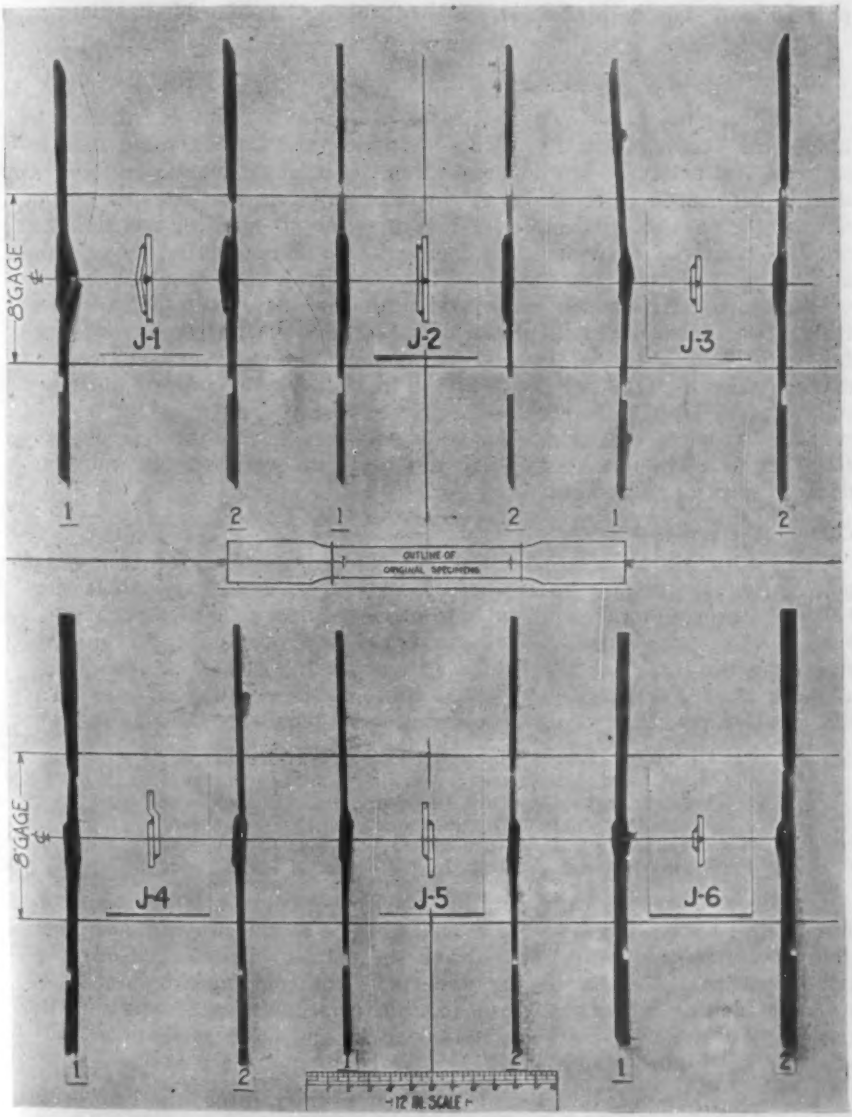

FIG. 4—JOINTS HAVING AN ABRUPT ECCENTRIC CHANGE IN SECTION (SIDE VIEW)

the effects of the abrupt eccentric change in section due entirely to the added metal. The following are the comparative results based on those for *P*-1:

	J-3[2]	*P-4*
Ultimate strength	95 per cent	100 per cent
Yield point	100 per cent	100 per cent
Energy of rupture	57 per cent	66 per cent

The results are practically the same, showing the major loss as compared with *P*-1 to be in the energy of rupture. Considerable bending was also in evidence.

TESTS OF DUCTILE ADAPTABILITY TO OVERSTRAIN

In a great many cases the ultimate failure of a joint is initiated by incidental bending stresses. These stresses are due to some form of eccentricity existing in the connection. Although plastic as well as ductile deformations are involved in bending, it is the extreme tension fibers which are affected most. When an eccentric member has sufficient ductile resistivity to endure the incidental bending induced by an axial adjustment to direct stress, some of the fibers may have been dangerously overstrained. Any additional overstraining would result in a complete failure by rupture, should the adjustment have alleviated all conditions for additional overstraining by permanent deformation and a small margin (say 15 to 20 per cent) of the local energy of rupture remained in the most highly overstressed extreme fibers. The material may be regarded as perfectly suitable for additional straining within the primary elastic limit. The new elastic limit developed by overstraining would undoubtedly be much higher.

Effects of Overstraining

The effects which are to be described have been observed from plain plate specimens similar to *P*-1 which, of course, is of measurable size; however, the results are applicable to any local fiber of a member regardless of size. Specimen *P*-3 was overstrained nearly to its ultimate strength; the load was then removed and an interval of 16 hours rest allowed, after which the load was continued to the point of rupture. The comparative results in terms of a normal slow tensile test are as follows:

Ultimate strength (increased)	1 per cent
Yield point (increased)	47 per cent
Total energy of rupture (decreased)	21 per cent
Remaining energy of rupture	74 per cent
Total energy of rupture (loss)	5 per cent
Permanent deformation	24 per cent

A temporary overstraining of this magnitude could not possibly prove detrimental to the long life and security of the metal, providing no additional overstraining were imposed and the permanent deformation properly taken up. A metal having undergone the cold-working process of strain-hardening, as in this case, exhibits the qualities associated with greater hardness; for instance, it is tougher and more resilient as indicated by the higher elastic limit.

Specimen *P*-5 was subjected to indefinite overstraining, the load being applied and removed steadily and without rest until rupture occurred.

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The results were a new elastic limit and yield point for each consecutive application of the load, the total permanent deformation increasing and the energy of rupture decreasing for each repetition.

The results are more comprehensive in tabular form and are given in Table I, also in the stress-strain curve (Fig. 2).

The gradual loss in ductility as given by the figures for energy of rupture may be regarded as the progressive nature of failure developed by

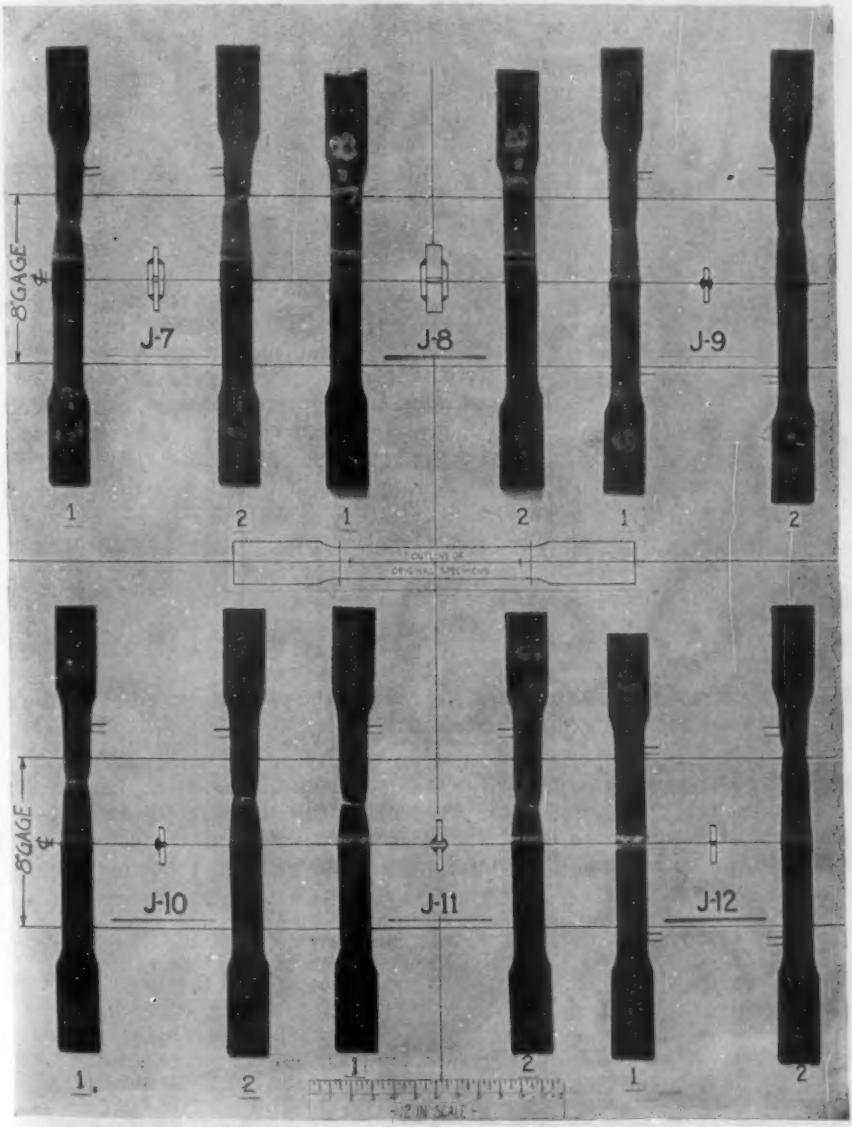

FIG. 5—JOINTS HAVING AN ABRUPT SYMMETRICAL CHANGE IN SECTION (FRONT VIEW)

continued or indefinite repetitions of overstrain. The energy of rupture is seen to be gradually absorbed until final rupture ensues. Each repetition produces a new and distinct group of properties. Incidentally, the quality of a metal after any amount of overstraining cannot be determined by a single test without knowledge of its previous strain history.

For comparative purposes the dotted line *a*, representing a less ductile metal, has been superimposed on Curve *P*-5. The computed results in

TABLE I

RESULTS OF TESTS ON SPECIMEN *P-5*

Stress Repetition Number	Yield Point (Lb.)	Remaining Energy of Rupture (Ft-lb.)	Permanent Deformation (In.)
1	36,000	3,845	0.05
2	36,700	3,785	0.24
3	40,700	3,540	0.31
4	43,400	3,460	0.48
5	47,400	3,190	0.58
6	48,700	3,040	0.68
7	50,700	2,650	0.83
8	52,000	2,230	1.08
9	53,400	1,560	1.52
10	54,000	890	1.90
11	50,700	140	2.33
		Rupture	2.45

TABLE II

COMPARATIVE RESULTS FROM LESS DUCTILE METAL

Stress Repetition Number	Yield Point (Lb.)	Remaining Energy of Rupture (Ft-lb.)	Permanent Deformation (In.)
1	36,000	1,800	0.25
2	36,700	1,740	0.24
3	40,700	1,495	0.31
4	43,400	1,415	0.48
5	47,400	1,145	0.58
6	48,700	995	0.68
7	50,700	605	0.83
8	52,000	185	1.08
		Rupture	1.20

Table II permit a direct comparison which shows that ductility is the criterion for adaptability to overstrain.

As a means of comparing the ductile quality of the weld metal with that of the base metal, a special eccentric specimen was used. The general dimensions and gage length were made the same as for the other specimens, the difference being in an eccentric offset at the center, intended to induce bending. The tests were made with the following specimens:

PE-1 and *2* ..... Plain plate
WE-1, *2* and *3* ..... Finished butt weld
WE-4 ..... 10 per cent reinforced butt weld
WE-5 ..... 20 per cent reinforced butt weld

The results for *PE*-1 and 2 are:

	PE-1	*PE-2*
Ultimate strength in lb.	60,000	60,000
Yield point in lb.	33,400	33,400
Elongation (percentage)	21.6	18.1
Energy of rupture in ft-lb.	3,000	2,330

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The lack of ductility in the weld metal is clearly demonstrated in the results for specimens *WE*-1, -2, and -3 based on *PE*-1, which follow:

	WE-1	*WE-2*	*WE-3*
Ultimate strength	78 per cent	75 per cent	71 per cent
Yield point	100 per cent	100 per cent	100 per cent
Elongation	2.7 per cent	2.7 per cent	1.4 per cent
Energy of rupture	13 per cent	12 per cent	8 per cent

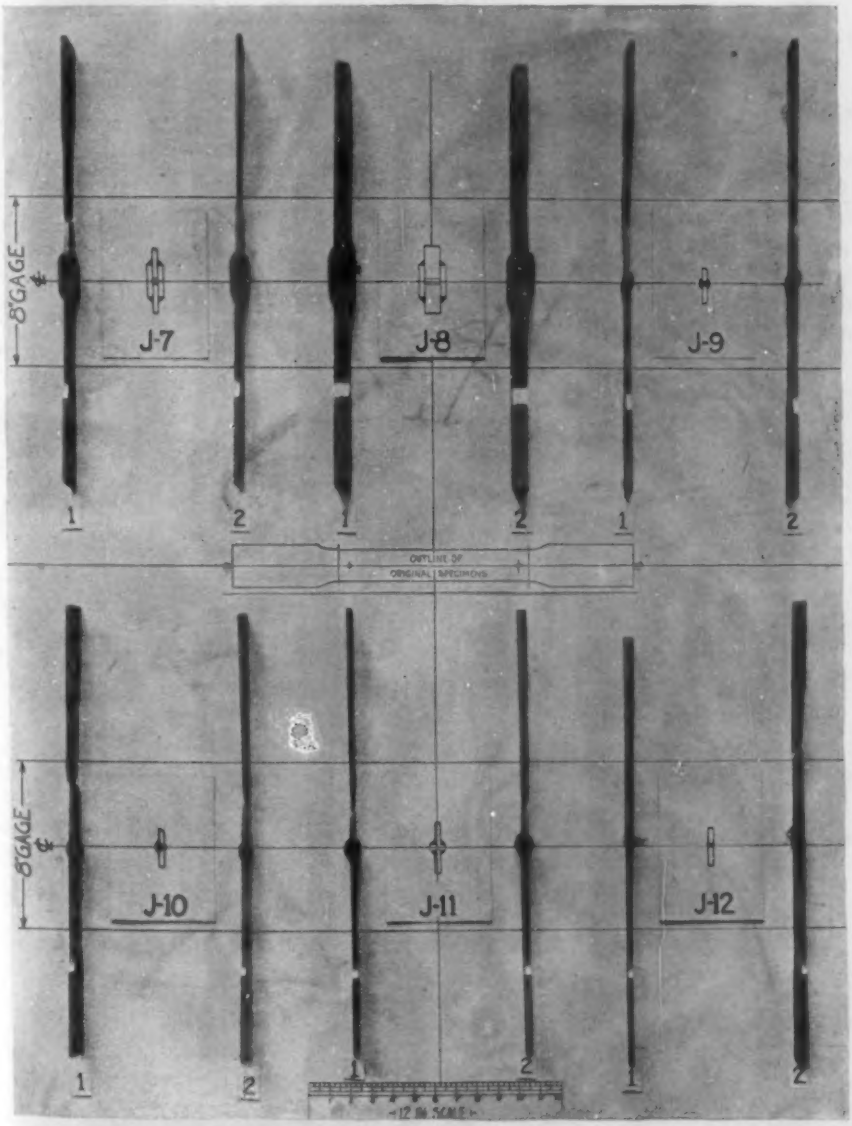

FIG. 6—JOINTS HAVING AN ABRUPT SYMMETRICAL CHANGE IN SECTION (SIDE VIEW)

The effectiveness of reinforcing a weld against lack of ductility is evidenced by the results obtained for *WE*-4 and -5, which are given as follows in terms of *PE*-1:

	WE-4	*WE-5*
Ultimate strength	110 per cent	110 per cent
Yield point	112 per cent	112 per cent
Elongation	74 per cent	103 per cent
Energy of rupture	70 per cent	103 per cent

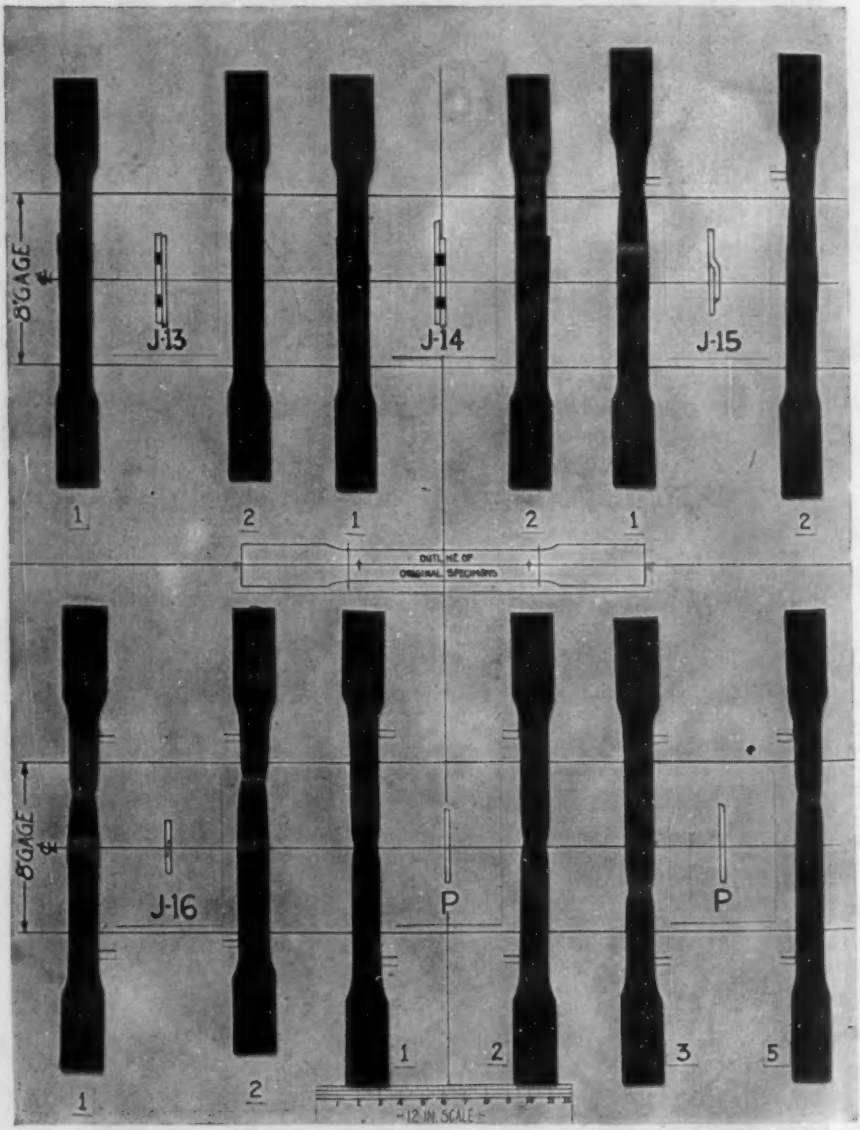

FIG. 7—SPECIAL JOINTS AND PLAIN PLATE SPECIMENS FOR TEST AND COMPARISON

Having only 10 per cent reinforcement, *WE*-4 broke in the weld, which accounts for the lower ductility. Probably a 15 per cent reinforcement for *WE*-5 would have been as effective as 20 per cent.

Plug Welds

Specimens *J*-13 and *J*-14 (Fig. 7) are two types of plug welded joints.

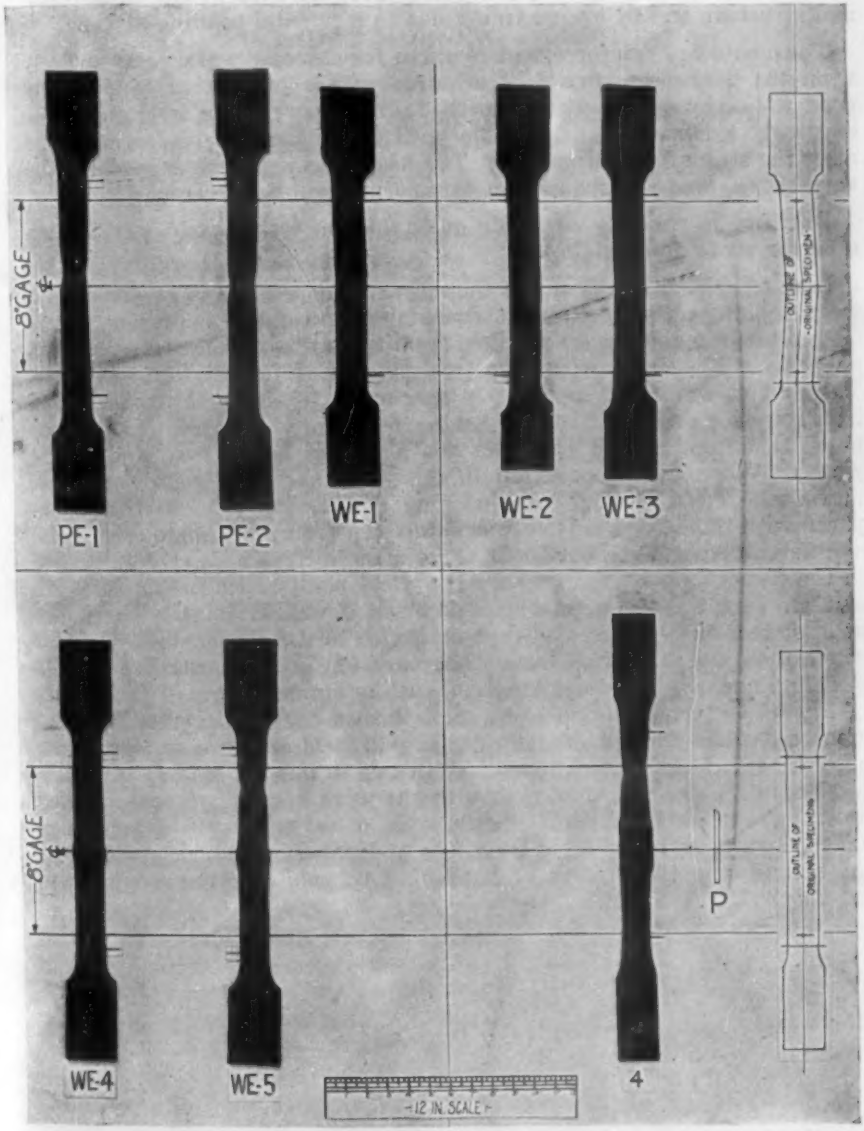

FIG. 8—SPECIAL ECCENTRIC SPECIMENS FOR INTRODUCING BENDING STRESSES DURING TESTS

These welds are not intended to develop the full strength of the plates joined, but as an indication of the strength of this type of weld. The results of test are shown in Figs. 1 and 2.

General Conclusions

Ample reinforcement and fillets of proper size offer the most practical means of insurance against failure by irregularities in the weld metal and structure and by overstraining due to incidental bending stresses.

The amount of reinforcement required for any case will depend entirely upon the degree of perfection acquired in the production of normally good welds, by any particular method; in any event the weld should be as nearly symmetrical as possible with just sufficient reinforcement to meet the strength requirements. The nearer an approach is made to the variable (*a*) and (*b*) the more nearly normal will be the results.

Ductility is a highly desirable quality in mild steel weld metal when used for structural welding.

Lack of penetration is one of the most common faults to be found in a welded joint and is especially detrimental when bending is present.

In reviewing the results obtained from the stress-strain curves, certain phenomena associated with different manners of failure were observed. The first case is most apparent in specimens J-3^1 and J-5^1 which failed in the welds; and J-3^2 and J-5^2 having failed in the plates. (It will be noted that each pair of specimen had a failure in the weld and in the plate.) When failure occurred in the weld, a higher yield point and ultimate strength with a corresponding decrease in elongation as compared with those for the plate was obtained. From the second case, quite a different result was obtained. Specimens J-9^1, J-9^2, and J-12^2 failed in the plates with similar increases in yield point and ultimate strength and an exceptionally good elongation for a welded joint. There are at least two likely sources of explanation as to the circumstances out of which these abnormalities arise. They are (1) strain-hardening by cold working, and (2) rapid deformation, such as might approach the nature of impact as from a single blow. It is known that the results from increased hardness or sudden deformation will yield results similar to those obtained for the cases mentioned. With this in mind it seems reasonable to assume for the first case that with the work of rupture concentrated in the more brittle and less ductile weld metal the rapid deformation which ensued probably approached the suddenness of impact, while for the second case the process of hardening by cold working would seem most logical.

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Discussion Papers Presented at Fall Meeting, A.W.S.

TUESDAY MORNING SESSION

September 23, 1930

THE first Technical Session of the Tenth Fall Meeting of the American Welding Society, held at the Congress Hotel, Chicago, Ill., Sept. 22-26, 1930, convened at 10.30 o'clock, Mr. J. J. Crowe, member of the Executive Committee of the Society, presiding as Chairman.

Discussion paper on "Arc Welding of Aluminum" by Mr. W. M. Dunlap, Aluminum Company of America.†

Chairman Crowe: You have all heard this most interesting paper by Mr. Dunlap. It differs from a great many papers in that instead of dealing with broad generalities it has given some very definite information and I feel sure that a large number of those present will want to discuss this paper.

Mr. Thomas S. Gaylord (Eastman Kodak Company): I should like to know what amperage he uses.

Mr. Dunlap: The amperage, of course, will depend upon the size of the rod and the thickness of the material. For a ⅛-in. rod the amperage will vary from 85 to 100 amperes, depending upon whether it is a fillet weld or a straight butt weld, and somewhat upon the thickness. For a 3/16-in. electrode the amperage will vary from 100 to 125 amperes, depending upon conditions.

Mr. R. Kraus (Westinghouse Electric & Manufacturing Company): Mr. Dunlap, do you preheat aluminum castings? Do you do much experimenting with the welding of such castings?

Mr. Dunlap: We have done some experimental work with the welding of aluminum castings, and whether or not preheatitng is necessary will depend upon where you are going to make the weld. If you have rather thin sections in complicated castings with strengthening ribs or thin sections joining to the heavier sections, or if the places you wish to weld are surrounded with solid metal, it may be necessary to preheat. However, if the casting is fairly heavy and you have uniform cross-section, or if the repairs are to be near the edge of the casting, preheating will not be necessary. If you are going to weld at a point in the middle of the casting which is surrounded by cold metal, that point is going to expand with the heat, and you are likely to crack the casting if you don't preheat it.

Mr. Kraus: Do you feel that you should clean the casting before welding? Do you use any kind of back-up bar or anything of that kind?

†Paper published in the October, 1930, issue Journal A. W. S.

Mr. Dunlap: In welding castings, if the weld has to penetrate clear through, for instance, if it is a crack and we want to go through a heavy casting, we can weld on one side and then turn it over and weld on the other. If it is a light casting, say ⅛ or ¼ in. thick, we use a backing strip, either steel or copper. We prefer to use copper as we find it gives a better, cleaner weld.

Mr. Clay W. Roberts (Pennsylvania Railroad Company): In welding or filling up of holes in an aluminum casting, is it necessary to countersink or prepare the hole? Would that be an advantage, and would it be necessary or advantageous to preheat in order to prevent cracking after the hole has been filled?

Mr. Dunlap: Cleaning the hole depends upon conditions. If you have a cavity in a casting that is full of sand or dirt, it is advisable to clean it out, so as to get a clean cavity to fill. If it is just a blowhole or cavity that is clean, it isn't necessary to do any tooling or cleaning out.

Mr. Roberts: Preheating, then, in filling holes would be the proper procedure, would it not?

Mr. Dunlap: It depends upon the location of the hole and the casting. If you have a small hole to fill in the casting near the edge, or if the edge of the casting is broken off, it may not be necessary to preheat. If you are going to bring the casting up to a very high temperature and if the weld will be surrounded by cold metal, it is advisable to preheat. As you know, the thermal expansion of aluminum is high and expansion must take place when heat is applied. In the case of a casting, the metal surrounding the point at which heat is applied must be heavy enough and have enough ductility to withstand the strain incident to expansion, or cracking will result.

Mr. A. Ralph Eckberg (Eastman Kodak Company): What is the condition of the metal adjacent to the weld once you have welded with the arc welding method? Is the tensile strength equal to that of the original metal? What is the condition of the weld proper? Do your tests indicate what kind of tensile strength you get in the weld itself?

Mr. Dunlap: The weld proper is in a chill cast condition. The cast metal has a fine grain structure and is very sound. The metal adjacent to the weld is, of course, in the wrought condition and the strength of the metal adjacent to the weld will depend upon the alloy that is being welded and the original temper of this alloy. If annealed material is being welded, the welded section will develop 100 per cent strength efficiency. If hard rolled or cold drawn metal is being welded, the strength will be between that of annealed material and cold worked material. The metal adjacent to the weld will not be fully annealed by the heat of welding. Cold rolled material will exhibit the following zones after welding: Cast metal in the weld proper. An area approximately 1/16 in. in width, depending upon the thickness of the material, that has been partially annealed by the welding heat. Beyond this area the sheet will not be affected by the heat of welding. The partially annealed area immediately adjacent to the weld is the point at which failure will occur if test specimens cut across the weld are

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pulled. In the case of a heat treated alloy, the following zones will be observed: The weld proper will be in the cast condition and immediately adjacent to this will be an area that has been raised to the heat-treating temperature by the welding heat and received an air quench. Adjacent to this area will be a third area that has been partially annealed. Following this will be a fourth area that has been artificially aged and this artificial aging will probably have caused excessive precipitation at the grain boundaries. Beyond this zone will be the original unaffected material. In the case of welded heat treated alloys, the fourth, or over-aged, area usually constitutes the weak link. This is assuming, of course, that the weld is properly made and the cast metal in the weld proper has been built up so as to be somewhat thicker than the sheet being welded.

The weld as made, in 17SI (duralumin), will develop a tensile strength of 40,000 lb. per square inch, as compared with 55,000 lb. per square inch for the original material. If we hammer the weld cold after the welding is completed, we will raise the tensile strength to approximately 45,000 lb. per square inch. If we heat treat after welding we will raise the tensile strength to around 48,000 lb. per square inch. If we hammer the weld cold and then heat treat we will get a tensile strength of about 51,000 lb. per square inch. Some work is of such a nature that it is not practical to hammer it. There are not very many fabricated articles that it is practicable to heat treat. After heat treating, in order to obtain the proper corrosion resistance, the metal must be water quenched. Quenching means some distortion.

Mr. Eckberg: The best thing to do is to use annealed aluminum to start with.

Mr. Dunlap: Yes, if the annealed aluminum is satisfactory for the purpose. Of course sometimes one wants a harder material, a stronger material, and therefore annealed material cannot be used. In that case we can often make the joint in such places that maximum strength or stiffness is not required immediately at the joint.

Professor C. A. Adams (Harvard University): I should like to ask in the case of duralumin, where you need the maximum strength, what is the fatigue or endurance limit of the weld? How does it compare at the affected joint near the weld with that of the original metal?

Mr. Dunlap: I don't have sufficient data to give you a definite answer to that question. We are collecting some data on that right now. The fatigue properties of the material right adjacent to the weld will be practically the same as that of the base metal, but at the weld itself of course they will not be the same. Duralumin in the cast condition is probably the most brittle commercial aluminum alloy we have. While the weld has more ductility than the casting, the elongation is low. As welded, the elongation in the weld will probably be in the neighborhood of 5 per cent, as compared with 18 per cent in the base metal, and as we hammer the weld we raise the elongation to perhaps 7 per cent. When we hammer and heat treat the weld we raise the elongation to 10 or 12 per cent, but our best elongation is not more than 60 per cent of that of the original material. In tension or compres-

sion, the strength is high, almost approaching the original material, but the ductility of the weld is rather low.

Chairman Crowe: I wonder if Mr. Timken of the Aluminum Company of America would care to contribute something to Professor Adams' question.

Mr. Timken (Aluminum Company of America): With regard to the fatigue or endurance limit of the material, we know that the endurance limit, as determined by the rotating beam type of specimen, of annealed duralumin is about 13,000 pounds per square inch. These results are predicated on 500,000,000 cycles of stress. After heat treatment it goes up to the neighborhood of 15,000 to 16,000 pounds per square inch in the region of the weld, which is the same as cast metal, and we don't have convincing data on such material. The cast alloys, which correspond most nearly to duralumin, are sufficiently far away in chemical composition that I think it would be a mistake to try to say that the results obtained on them are those to be expected in the cast duralumin that occurs in the case of a weld.

That is about as far as our information today will allow us to answer that question specifically. As Mr. Dunlap pointed out, we have a whole battery of machines and we have just started on this problem, but it is too early to give results because of the long time involved in making such tests.

Mr. James W. Owens (Welding Engineering & Research Corp.): Mr. Dunlap has stated that the porous aluminum weld has a higher strength than one that is not porous. I should like to know how he obtains that information.

Mr. Dunlap: I don't mean to say that a porous weld has a higher strength than one that is not porous, but we have found that in spite of the slight amount of porosity in arc welding, we get better strength than we do in torch welding. The porosity is not bad. There are a good many pores but most of them are too small to be seen with the naked eye, except in a very light section. Material from .064 inch up to about one-eighth inch thick welded with the metallic arc often shows this fine porosity. When we get into heavier material, from one-eighth to one-quarter and up, there is practically no porosity and we get very sound welds. The freezing of the material is more slow, so that the gas has a better chance to escape, whereas in the light material the solidification is almost instantaneous and the gas is trapped in the weld. It is just simply a fine gas pocket, no other inclusions are there.

Professor Adams: Would welds of this variety be satisfactory in airplane structures or machinery where the welds are subject to fatigue failure?

Mr. Dunlap: At the present time I wouldn't recommend the welding of aircraft structures. Those structures are subjected to severe vibration strains and I would not recommend it, although some people are doing it.

Chairman Crowe: I wonder if Mr. R. R. Moore of the Wright Company would care to contribute to Professor Adams' question.

Mr. R. R. Moore (Wright Company): The welding of major stress parts on either aircraft construction or aircraft engines is prohibitive. We don't do it at all. In fact, we know too little about the strength of welded aluminum alloys. One gentleman asked as to whether blow-holes should be welded and whether they should be preheated. We think it is better practice, in the case where you have blow-holes in the casting and where they are not in a stressed location, to solder rather than weld, the idea being just a matter of appearance. That is, I don't believe that you help the strength of a casting by welding up a blow-hole. Where there is any welding to be done, we always preheat the casting. Of course it is much more important to preheat the casting when the casting is a complicated section, with various large and small dimensions. In any case it is standard practice to always preheat the casting where welding is done. In some cases Army and Navy requirements are that parts be not welded if there are blow-holes to be cleaned out, so that you get to the bottom of the blow-hole. They will even prohibit soldering. In some cases to improve the looks of the casting we do solder. As I said before, welding is not desirable to fill a blow-hole because it doesn't improve the strength of the casting a bit.

Mr. Gaylord: I wanted to ask how he welded Alclad.

Mr. Dunlap: Alclad can be welded just the same as uncoated metal.

Mr. Gaylord: What is that composed of?

Mr. Dunlap: The coating or the core?

Mr. Gaylord: I understand the aluminum is on one side and the base metal on the other.

Mr. Dunlap: Alclad 17ST (duraluminum) consists of a core composed of 17ST that has a thin coating of pure aluminum on either side of it, which protects the core against corrosion in the same manner that zinc protects galvanized iron.

Mr. Gaylord: I thought it was another base metal.

Mr. Dunlap: A very thin coating of pure aluminum on either side of the 17ST core.

Mr. J. C. Lincoln (Lincoln Electric Company): I understand Mr. Dunlap to say in the first part of the paper that the aluminum as it drops off the end of the electrode would tend to go to the cold part of the plate rather than to the hot part of the plate. That is so different from the practice that we are acquainted with in steel welding that I wanted to bring that point out and find out what the facts were.

Another thing I should like to inquire about is this: Is the coating on the outside of the electrode of such a nature that to some extent it encloses the arc so as to prevent the air striking the arc.

Mr. Dunlap: I probably didn't make myself clear in the first part of the paper. The point I was bringing out was that the arc would tend to draw from a cold point on the end of the electrode rather than from the hot spot, and not that the metal would go from the electrode to the cold spot on the base metal. In other words, if we use an

uncoated rod the arc will tend to run round and round the rod, instead of coming off steadily. This fluctuation in the arc gives an unstable current, and the biggest trouble we have is from the aluminum coming off in large drops instead of passing off in very small globules. The flux coating on the rod has a slightly higher melting point than the rod itself so there is a sheath immediately around the arc at the end of the electrode. The sheath practically touches the base metal, but not quite.

Mr. Lincoln: So that the sheath very largely prevents the air from striking the melting aluminum?

Mr. Dunlap: Yes.

Mr. Ralph Warrender (Westinghouse Electric & Manufacturing Company): I should like to ask Mr. Dunlap to what extent aluminum arc welding has been applied to large receptacles of plate aluminum, for instance, in tank work, and in places where you don't have an edge to work on, where you work in the center of a large plate, where you have great heat radiation?

Mr. Dunlap: Arc welding, to the best of my knowledge, has not been used as yet on tank work or material of that kind. Its greatest use has so far been in architectural work, door frames, window frames, and doors. We are getting started on some investigational work in connection with the welding of tanks and I see no reason why it won't work out very well. As you probably know, arc welding of aluminum is something that has been developed in the last few months and the field hasn't been very thoroughly covered as yet.

Mr. N. Mayhew (Westinghouse Electric & Manufacturing Company): I should like to ask Mr. Dunlap, when he is welding two thin plates, say one-eighth inch plates, does he have any trouble with porosity when he just starts the weld?

Mr. Dunlap: We find no more porosity there than we do anywhere else in the weld. In using a backing strip on a butt weld, we usually strike our arc on the backing strip at the edge of the metal, and then proceed down the seam. That keeps us from having trouble at the edge of the weld. We have no trouble with porosity at the beginning or end of the joint.

Chairman Crowe: If there are no more questions we will close the discussion at this point. At the end of the session if there is any time remaining we will again open this paper for any further discussion that you may care to contribute.

The next paper on the program is the one that is listed first, "Welding of Stainless Steel," by Mr. L. W. Hostettler, of the Allegheny Steel Company. I believe he is here now.

Paper and Discussion on "Welding of Stainless Steel," by Mr. L. W. Hostettler, Allegheny Steel Company.

Mr. L. W. Hostettler: The alloy, containing 18 per cent chromium and 8 per cent nickel, is non-magnetic and doesn't respond to heat treatment in any way. It has about one and one-half times the

expansion coefficient of mild steel, which creates expansion and contraction problems when welding. It has an even higher electrical resistance than the straight chrome irons, which is another point that must be considered when arc welding is used. The thermoconductivity of the 18-8 alloy is slightly less than one-half of that of wrought iron, whereas the straight chrome stainless iron is about two-thirds of wrought iron.

The successful welding of those alloys depends entirely upon the proper technique, the proper electrodes and the proper flux, particularly the flux.

The straight chrome irons can be welded either by the oxyacetylene flame, the metal arc, carbon arc, resistance spot, or the compression butt weld. In the use of the oxyacetylene method, it is necessary, if you want to secure a good sound weld, one that is free from porosity, to use a flame that is slightly reducing. Great care must be taken not to deposit any carbon in the weld as this has caused quite a number of failures in welded sections.

Metal arc welding is recommended, but is not practicable on anything lighter than a No. 14 gage sheet. For lighter gages than this we recommend the oxyacetylene method of welding.

I mentioned the fact that the electrical resistance of the straight chrome iron was higher than mild steel. That means that it is not necessary to use as much power input as would be used in the same gage material in steel. We have found that a short arc makes a much sounder weld than the long arc. Incidentally, I might say that most of the welds that are made on these stainless alloys are called upon to be practically 100 per cent perfect, so far as porosity is concerned, and in the chemical analysis of the weld itself.

A great deal of spot welding is being done, and very successfully. It is a matter for the operator to determine by experience what pressure, time and power input to use for given gages of a given alloy. We have seen spot welding that is being done commercially and regularly, where there is practically no burning or pitting of the welds.

Welds made in straight chrome irons become air hardened, as the metal has been heated above the critical temperature, and the welds become fairly brittle, particularly when using chrome content of 12 to 16 per cent. With the higher chrome content there is not as much air hardening.

The method of annealing that is most generally used is to bring the material up to about 1425 deg. Fahr. and air cool it. The other method is to bring it up above its critical point, which is about 1500 deg. Fahr., and then bring it back and temper it the same as you would in the case of ordinary high carbon tool steel or other similar material.

When you want to remove a bead by grinding, use a so-called soft wheel that will not take too much time, or raise the temperature unduly.

One of the big problems in welding of these alloys is to keep them

from going out of shape, which, of course, depends altogether upon the shape and design of the piece that you are welding.

There is actually more welding being done on the 18-8 chrome nickel alloys and therefore there is more interest in these than in the straight chrome irons. These alloys have the characteristics that I outlined a minute ago. One is the extremely high expansion coefficient and the other is the extremely low thermal conductivity.

In welding these properties sometimes cause trouble. In tank work, for instance, where you are making tanks of this alloy of several thousands gallons capacity, it requires quite a bit of skill on the part of the operator to weld long seams in 12 gage or 10 gage sheets, and not have them buckle.

Arc welding is recommended as it is quicker, and the heat doesn't get an opportunity to travel over as great an area of the sheets.

In welding these alloys by oxyacetylene on many shapes and sections it is necessary to use jigs and chill plates to keep the heat from buckling the piece.

We have found, incidentally, in checking up on some failures of welded sections in that particular alloy, that at times the carbon has been built up in the weld as high as .40 to .60 per cent. That was caused, we found, by the flux that was used on the rod. It is necessary, of course, to use a coated rod, in arc welding, whereas this is not necessary in oxyacetylene welding this particular alloy. The flux that is used should contain no graphite or any other carbonaceous compound to react and raise the carbon content of the weld metal.

The chrome nickel alloy is generally furnished with a maximum of about .16 carbon. There are certain applications where it is necessary to have a slightly higher carbon content. Ordinarily, it is best for welding to have the carbon under .10, and to have a welding rod that is low in carbon and preferably rather high on the chromium side. The ordinary range of chromium is 17 to 20 per cent with 7 to 10 per cent nickel. A certain amount of the chromium is lost during the welding operation. Therefore it is recommended that the rods have in excess of 18 per cent chromium with a maximum of .10 carbon.

The 18-8 alloy is a so-called austenitic alloy in that it is non-magnetic, does not respond to heat treatment and the carbon is in solid solution at all temperatures. If, however, service requirements of the fabricated material will involve temperature ranges, from 1000 deg. Fahr. to about 1550 deg. Fahr., for certain applications, it will be necessary to anneal the piece after it is welded.

The only one way to do this properly is to anneal the entire piece of equipment after welding. This sometimes is quite troublesome to the fabricator, because he doesn't have furnace equipment large enough and of the proper type to do it, but nevertheless the manufacturers of this particular type of alloy know that it is absolutely necessary for certain applications.

One use to which this alloy has been put to a very large extent is in kitchen equipment and things of that sort. You can weld with either

gas or arc and you need have no fear of failure adjacent to the weld due to what is known as intercrystalline corrosion.

The proper annealing temperature is 1800 deg. Fahr., up to 2000 deg. Fahr. Naturally, if you are annealing at 2000 deg. the time will be much shorter than if you are annealing at 1800 deg. Of course, the time will depend upon the cross-section of the piece that you are heat treating or annealing.

If you were going to build containers for nitric acid, to which that particular alloy is very resistant, it would be necessary to anneal after welding. On the other hand, if you are building equipment of this alloy for the dairy industry it is not necessary to anneal, even though certain types of dairy apparatus are jacketed and subjected to brine and water and air.

One company that is using welded sections of this alloy in strip has developed a special machine which welds material that runs about .010 to .012 inches in thickness in one twelve hundredth part of a second. That is pretty quick. The strip they are using is furnished to them with a minimum of 225,000 pounds tensile, and it is hardly possible for them to anneal it. They have made tests on corrosion and have found quite a difference between the welding as they are doing it with an extremely short time element as compared to the spot welding that is ordinarily done.

I mentioned intercrystalline corrosion and that failure is likely to occur in certain applications with that alloy adjacent to the weld. I should like to give you an illustration. Take a piece of alloy and weld it by the arc or by the oxyacetylene method, using the proper technique. Physical tests may show it to be about as near perfect as you can get it. You can hammer it, you can do all sorts of things with it, tie it in a knot, figuratively speaking. Take the piece and cut it in two after it is welded and anneal one half of it at 1800 to 2000 deg. Fahr. Then subject both of those pieces to an accelerated corrosion test, the one that is welded and annealed and the one that is welded and unannealed. You will find, for instance, that after 150 hours the piece that was not annealed will show a failure adjacent to the weld, while there will be no failure in the piece that has been annealed.

Manufacturers prefer to have the users of this alloy take up with them what it is going to be used for and let them assist in solving the problems in order to prevent troubles.

I should like to point out an example in connection with welding and misapplications. A concern manufacturing food products used this alloy very successfully in the handling and manufacturing of mayonnaise. Quite a bit of their equipment and machinery was welded. To this manufacturer welding was a cure-all, apparently, because he found that it stood up beautifully in the egg yolk, though he wasn't so sure about vinegar. He tried it in vinegar and used it regularly for about two years and a half, and it worked fine. He therefore decided to have a storage tank built for his vinegar with welded construction. He specified 14 gage, welded. He didn't specify whether

it was to be welded by the arc or gas method. He didn't specify whether it was to be annealed after welding. All he specified was: a welded tank, polished inside and out. The tank went into service, oxyacetylene welded. In about three months it began to leak right through the weld, and failed. He blamed the welding.

We happened to be called in on the thing. You can picture our position, between the fabricator and the user. We told the company that had they consulted us before they had the tank installed we would have recommended against a welded type of construction, because it was a type of tank that it would have been commercially impossible to anneal after welding.

That particular plant finally came to the realization that it wasn't the fabricator's fault. He made a perfectly good weld, but it was a misapplication. Since then they ordered a tank made of three-sixteenths inch plate, riveted and caulked.

There is another point in connection with the welded sections. Much of this material is welded and used in the polished condition for the reason that, like all other metals, the surface has a lot to do with the resistance to discoloration, tarnishing and corrosion. There is where the tough problem comes with the welding, because in equipment of that kind, after welding, you have to grind off the bead and have it 100 per cent free from porosity and pinholes. Don't attempt to use too light a gage of material, because if you don't have enough metal to work with in welding you are just going to be out of luck.

That is a thing, incidentally, that a lot of fabricators have gone through. It is the most logical thing in the world for them to do, for the reason that this alloy is very expensive and they naturally try to cut their material cost down to the minimum.

I haven't said much about the actual technique of welding, and the reason I haven't, as I mentioned a minute ago, is that the technique varies greatly with the type of welding you are doing. The thought that I should like to leave with you is: When you have something to fabricate and weld, give the manufacturer of the alloy an opportunity of working with you. All of them have service welders. I know they are only too glad to send them to your plant and get you started off right. Their engineering departments will work with you, so far as design is concerned, and I assure you that there is a lot in the design in using this particular alloy.

I feel that this particular alloy, 18 per cent chromium-8 per cent nickel, is going to be used more and more all the time. There is no reason in the world that it can't be used successfully, provided the fabricator has the real picture of what its properties are and how to handle it. (Applause.)

Mr. W. B. Miller (Union Carbide and Carbon Research Laboratories): I heartily agree with Mr. Hostettler on knowing your metal and what you are going to use it for, but I cannot agree with him that we must use a reducing flame. It should be regulated to a neutral

flame, and with a choice of a proper flux it will give a good, dense weld with ductility and corrosion resistance to be expected from a cast metal. Since heat treating after welding reduces the corrosion resistance, would it not be best to have the manufacturer furnish a metal with the minimum amount of cold work in it for the welder? That has never been brought up, but it seems to me that if a chrome nickel alloy in an almost fully annealed condition is furnished the welder, the intergranular corrosion will be less in its effect, depending upon the amount of cold work in the metal.

Mr. Hostettler: Cold work of any kind tends to increase tensile strength. As an example, take a piece of alloy. Let's assume it is a plate or sheet. Take a pein hammer and hit it a good blow, and where you have struck the blow you have increased the tensile strength from around 90,000 pounds tensile in the unwelded state to around 115,000 or 120,000 pounds.

Incidentally, I might say that there is another factor that enters largely into the use of this alloy, particularly where you are handling highly corrosive electrolytes. That is the electrolytic action. You can get electrolysis in one piece of metal just as easily as you can in two dissimilar metals, because the minute you change the physical properties in that spot that I just pictured by hitting it a good hard blow with a hammer, you have changed the electrical potential from the main body of the sheet.

Mr. Kraus (Westinghouse Elec. & Mfg. Co.): Would you give us some details of the technique to be followed with rigid welds, as illustrated in Fig. 1. The insert "A" made from ⅜-in. non-magnetic steel is to be welded in the circuit breaker top "B." We have had diffi-

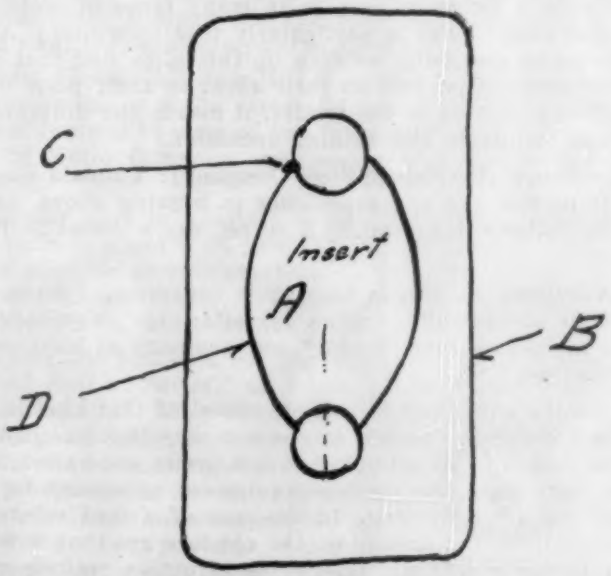

FIG. 1

culties welding non-magnetic steel, like most other users. We have tried it various ways. Beveling along lines "D" helps most, but is expensive; the beveling requires additional labor and the "V" must be filled with a high-priced rod. Buttwelding is the cheapest; a small gap is left at the joint and welding is done from both sides. However, cracks are apt to develop at "C."

Mr. Hostettler: In the case of welding three-eighths material you have a good many problems that enter into the picture. As this gentleman says, you can do it by beveling or you can do it by welding on two sides. You have certain characteristics in that alloy, particularly the expansion coefficient, so that with certain shapes sometimes you will find that if you preheat to a comparatively low temperature, say 400 or 500 deg. Fahr., it will help tremendously in getting away from fractured welds. We have seen many welds where the technique that was used in making them was perfectly all right, but the operator lost sight of the fact that he had a metal that had an extremely low coefficient of expansion.

I mentioned the steam jacketed kettle. Let's go back to that, for instance. You take the kettle and make it up in segments, and then take those segments and put them under a press, form them and then jig and weld. If you start out with 90,000 to 100,000 pounds tensile strength in the sheet, you may come out with 120,000 pounds in the formed section, and it doesn't take a great deal of cold work to bring it up to 120,000 pounds tensile. At 120,000 tensile you have good ductility as you still have around 35 to 38 per cent elongation, but you do have a very high yield point, about 80,000 lb. per sq. in. You can picture what happens in making a weld of that kind. If you can get rid of a certain amount of that expansion before you start to weld you will have a lot more success in many types of welding than if you make it cold. That is particularly true in winter. A lot of the fabricators who are doing welding on this alloy find that if they can put an ordinary steam line on their sheet or their plate or whatever they are going to weld in the winter, it means the difference between success and failure in the welding operation.

Mr. C. Schenck (Bethlehem Steel Company): I should like to ask the speaker if he has had any experience in brazing alloys, and also the practice he follows in annealing a vessel, say a vessel 30 ft. by 10 ft. in diameter.

Mr. Hostettler: So far as brazing is concerned, I have never seen brazing done successfully, I mean day after day. You have a peculiar condition in brazing, and, frankly, our company at least, recommends against brazing.

So far as the annealing of a large vessel of that kind is concerned, it is quite a problem. I know of one company that has just completed a tank car made of this alloy and it is a pretty good size. Fortunately for them, they have the furnace equipment necessary for annealing the entire job after welding. In the case of a tank where you don't have the facilities for annealing, the chances are that it would really be better to use a different type of construction entirely rather than

the welded construction, assuming that the liquid you are going to handle would be too active for an unannealed welded section.

Mr. Schenck: I assume that even if you had the facilities it would be very hard to heat it to 1800 or 1750 deg. Fahr. without collapsing.

Mr. Hostettler: The tank that I have in mind that was annealed was made of ⅜-in. plate. I think it was about 16 ft. in length and 6 or 7 ft. in diameter. That was annealed at 1800 deg. Fahr., but I will admit that there are very few plants that have the facilities to get up to that higher temperature for a vessel of that size.

Mr. R. W. Holt (Fusion Welding Company): I should like to ask what progress has been made in vertical and overhead welding with the metal arc on these alloys.

Mr. Hostettler: There has been very little, as a matter of fact. There has been so little progress that frankly I am not in a position to discuss it at all. We are working, incidentally, on fluxes right along, and, of course, a whole lot depends upon the flux for a job of that kind. Frankly, we haven't hit it yet.

Mr. C. M. Rusk (R. D. Thomas & Co.): I know of a place where they are welding in vertical and overhead positions with 18 per cent chromium and 8 per cent nickel electrode. In the hydro-electric plant of the Pennsylvania Water & Power Company at Holtwood, Pa., they are building up worn surfaces on cast iron gates.

They first stud the cast iron and then face this casting with material from a mild carbon steel electrode. On top of this they deposit the 18 per cent chromium and 8 per cent nickel for a corrosion and erosion resistant surface.

Chairman Crowe: I understand Mr. Chase, Associate Editor of American Machinist, McGraw-Hill Company, has something of interest to report on what they are doing at the Ford plant.

Mr. Herbert Chase (McGraw-Hill Publishing Company, New York City): Although this is not in direct discussion of the paper, I thought it might be of interest to some of you to know about a part of the work that the Ford Motor Company has done in their extensive use of the stainless steel.

The particular part in question is the rim used around the headlights. This rim is about 9 in. in diameter and is made out of a strip of stainless steel or of rustless iron. I understand that both have been used at different times. The strip is between .020 and .030 in. thick, and about 2 in. wide. The two ends are buttwelded together.

In developing the buttweld on this part the Ford Company experienced a great deal of "grief," as I believe everybody does who tries to weld stainless steel. They found in developing machines to do this job that they could make, in some cases, 200 or 300 welds quite satisfactorily, and then would run into a series of defective welds. Since they were producing in the neighborhood of 15,000 of these rims a day, it was absolutely necessary that they get a weld that would be practically 100 per cent perfect. A great deal of time and money was spent in developing a satisfactory welding machine.

One of the difficulties met was that the strip was thicker at the edge than in the center. This resulted in the dies having an unequal bearing and therefore giving an unequal current flow.

They experimented with variations in the current, in the time of the weld, and in the pressure employed. They used copper dies, then copper-tungsten dies, and finally they came to steel dies which were ground on the surface in order to get a perfect contact between the dies and the metal. Then they were able to make satisfactory welds consistently. Today, I am told, they have perhaps a dozen rejects out of a day's run of 15,000 pieces.

Professor Adams: Were they flash welds or just butted together?

Mr. Chase: A straight butt weld, as I understand it, although I did not actually see this job in progress. After welding, the flash is sheared off and the piece is put into a die and expanded and shaped to a convex contour, and then the two edges are rolled or spun over to complete the job. Hence the weld is subjected to very severe treatment. The pull exerted in the expanding dies is quite high and there must be no failures. Also, when the job is finished and ground, the weld has to be practically invisible.

Mr. J. C. Lincoln: Some years ago, in doing some carbon arc welding, I got some samples from the Allegheny Steel Company, three-eighths inch square bars, for this particular experimental work. These were welded with carbon arc with controlled atmosphere. The idea was to get in the weld a ductility of the weld metal which would be equal to the ductility of the parent metal, and for the metal alloy containing nickel there was no trouble. We got results very satisfactory in every way. In the case of an alloy containing chromium only (I was told this material was about 18 per cent chromium), there was no trouble about getting ductility, but at the end of the weld, after making a section through the weld, there was a hole about a quarter of an inch in diameter or something of that order. I was not able to get rid of it.

I should like to inquire of the author as to why I got that hole in the middle of the weld, and what I can do to get rid of it.

Mr. Hostettler: I would say the chances were that you had too much power input. Without actually going into it and seeing the operation and checking back, that is what I would say had happened.

Mr. Lincoln: The power input was similar for both alloys.

Mr. A. S. Wall (Dominion Bridge Company, Ltd.): We were asked by an educational institution in Canada to build a small experimental digester of chrome nickel alloy steel. As we had had invitations to quote on full-sized digesters of this metal we were pleased to learn something from the fabrication of a similar but very much smaller vessel.

Digesters are sometimes 18 ft. diameter and 50 to 60 ft. high, and when built of flange quality plate may have shells of perhaps 1⅜ in. thickness. Because the acid used in cooking pulp attacks steel readily,

necessitating expensive linings, the research institute wanted to try out a vessel of chrome nickel alloy steel without linings.

The experimental digester was made to standard shape and was fitted with top and bottom nozzles. These nozzles were of cast steel, but they were lined with welded alloy steel plate to protect them.

Connectings for fittings were made by drilling through the side wall of the top nozzle casting and its liner and inserting short alloy steel tubes or nipples, which were welded to the steel casting on the outside, and the alloy steel liner on the inside.

After being built, the whole vessel was annealed, and tested hydrostatically to 300 pounds per square inch.

In operation, after a few cycles of cooking, several of these short nipples failed, and upon investigation it was found that each had cracked in a plane normal to its longitudinal axis, and the location was just about the junction of the cast steel of the nozzle and its alloy lining.

I am curious to know whether this was from electrolysis or differential cooling or something else.

Mr. Hostettler: Those fractures occurred in the tubular section?

Mr. Wall: Yes, in the tubular section.

Mr. Hostettler: A digester is subject to temperature changes. If I am not mistaken, the temperature goes up to about 140 or 150 deg. C. There again is where your expansion coefficient affects the endurance limit of the material. Incidentally, on this particular job we know a lot more about it, you know a lot more about it, and it comes back to the very thing that I mentioned a while back, the matter of design, constructional details. There have been lots of failures of these alloys for this very reason. The primary cause was that it was not given a chance to breathe normally, and when you don't allow metal with an expansion coefficient such as this 18-8 alloy has, to have ample opportunity of breathing, you are bound to build up excessively high work strains in some localized area.

Professor Doan (Lehigh University): I should like to ask Mr. Hostettler whether he has found any advantage in having the alloying elements in the regular electrode or the coating rather than in the electrode itself. Then I should like to ask Mr. Dunlap, if he is still here, about the arc coming from the colder part of the electrode. That seems rather strange. Usually the cathode hot-spot seeks the hottest part of the globule rather than the coldest part. It is a rather extraordinary case.

Mr. Hostettler: I didn't just get that question.

Professor Doan: It is whether the incorporation of the alloy, perhaps chromium and nickel, or other metals, is more advantageous in the electrode itself, or in the coating upon the electrode. Is there any difference in the results?

Mr. Hostettler: We have been doing a lot of work along this very line. So far as we have gone, we find that it is preferable to have an

electrode with a very low carbon content and high chromium. Apparently we lose a certain amount of chromium during the welding operation. So far as the flux is concerned, the important thing is to keep out of the flux anything that will tend to increase the carbon in the weld.

Discussion paper on Oxy-Acetylene Welding of Corrosion Resisting Steels," by Mr. W. B. Miller, Union Carbide & Carbon Research Laboratories.†

Chirman Crowe: With the completion of Mr. Miller's paper it seems that we have covered the whole category of steels and alloys with the exception of the plain carbon steels. These papers are now open for discussion.

Mr. W. B. Miller: I am willing to admit that chromium and manganese steels weld very easily with the arc.

Chairman Crowe: I wonder if Mr. Bibber would care to state what the Navy is doing with some of these alloys.

Mr. Leon C. Bibber (U. S. Navy): Mr. Chairman. We are welding the gasoline storage tanks in all of the late naval construction. A great deal of gasoline is carried today in tanks down in the holds of the ships. Leakage from the gasoline tanks in the hold, even a very small amount, such as a continual dropping, would soon create a dangerous gaseous mixture. These tanks are used on what we call the hydraulic system. As soon as the gasoline is used, salt water fills in behind, so the tank is never empty. This is a very severe corrosion condition, and for that reason we have written a specification for the construction of corrosion-resisting steel tanks for gasoline storage. We are quite particular in our requirements, calling for annealing above 1600 deg., and requiring complete polishing in the inside of these tanks. We have outlined very extensive preliminary tests and tests of the tanks after fabrication, and we hope to get some very good results from these tanks.

Mr. P. J. Gurklis (Dow Chemical Company): Mr. Miller mentioned some alloys that would resist corrosion against various kinds of chemicals. No doubt he means that the presence of the alloying elements in special steels makes them corrosion-resistant. Over at the Dow Chemical Company we have trouble with cast iron pump housings. Hot brine is circulated through the pump housings at about 5000 feet per minute. They have been wearing out very rapidly. We have tried to build up the corroded away areas with various kinds of bronzes and the oxyacetylene torch. I am wondering what would be the best method to repair these housings.

Mr. Miller: Your trouble is erosion rather than corrosion, isn't it? Are there any salt particles in the brine? We have had the same trouble in our own plants. We find that very fine, solid particles of high impact and impingement give us an erosion rather than a corrosion effect.

Mr. Gurklis: We do get a more rapid corrosion as we increase the velocity of the brine.

†Paper published in the December, 1930, issue of the Journal of the A. W. S.

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Mr. Miller: I suggest you build them up with a wear-resisting alloy. There are several available.

Chairman Crowe: A large corporation like Bethlehem should have some data, and I wonder if Mr. Schenck would care to tell us what they are doing up there.

Mr. Charles Schenck (Bethlehem Steel Corp.): I don't believe I have anything to add, the subject has been covered so thoroughly this morning. I was listening to Mr. Chase and I should like to ask him one question about the welding of those rims, whether they were annealed after welding before they put the operation on or later.

Mr. Chase: I am sorry, I didn't quite catch what the speaker said.

Mr. Schenck: I should like to ask if those rings that were butt welded were annealed after welding.

Mr. Chase: I can't tell you that. I didn't actually see the process myself. That was not told to me.

Mr. Hostettler: They are not annealed.

Mr. C. S. Purves (Quasi-Arc Incorporated, Oak Park, Ill.): With regard to the handling of brine in pumps, probably an experience of some years ago may prove of interest. It was a question of both erosion and corrosion, complicated by a galvanic action. I had exactly similar trouble with stainless steel, but not that made by the Allegheny Company, another composition altogether.

In the ordinary way when these steels were tested out in the laboratory we found that they gave a very wonderful resistance to ordinary sea water, but when used in valves or valve stems in the working end of a marine ship service pump (which was a bronze casting), that is, where we were using salt water all the time, we found on the ship's journey to Australia and back that these stainless steel valves, which were giving such wonderful results in the laboratory, were practically all gone. The question immediately arose there: What is the cause?

Well, to my mind, the cause was one of galvanic action attacking those pieces which were of a ferrous base construction, when the castings were of a non-ferrous base. The galvanic action occurred on the ferric base material. To overcome the trouble we bolted small pieces of wrought iron or cast iron into the bottoms of those castings. We entirely got rid of the trouble. After a period of six similar voyages the pumps were opened up and the chambers thoroughly examined. There was no question of that erosion having taken place because the stainless steel was resisting galvanic action and the ordinary piece of mild steel—or cast iron—had completely vanished. Perhaps that little experience might assist our friend.

There is still a further point that may be permitted in reference to Mr. Hostettler's paper. That is with regard to the covering of the electrode. The analysis of the electrode and the position of welding. The electrode which I have in mind has absolutely no graphite content whatever in the covering. The electrode itself is composed of a specially designed steel, the carbon content of which is 1.80, the

chromium 22 per cent (to allow for evaporative losses). It is also essential that the current conditions are very critical. Otherwise you are going to have all sorts of troubles. The critical current conditions must be such that you have very little (permissible variation) in the length of the arc, which must at all times be held short. The job must not be allowed to become too hot. As I understand what Mr. Hostettler mentioned, he recommends nothing less than 14 gage material to be welded. I quite agree with him, but there are other things which enter into that subject, especially in connection with the manufacturers regarding the cost of stainless steel. There are quite a number of instances where cost is the predominating factor and must be taken into consideration. Where a manufacturer will not pay the cost of 14 gage material he will pay the cost of 16 gage. In fact he would like to go to 20 gage, which would be good enough for certain purposes. I have successfully welded 20 gage Allegheny, of course, of the 18-8 (austenitic class), but I would not put it forward as a commercial proposition. Sixteen gage is a commercial proposition—that can be handled either on the flat, vertical or overhead positions.

Mr. Charles M. Rusk: Was that oxy-acetylene or arc welding?

Mr. Purves: Arc welding.

Chairman Crowe: I think Mr. Miller says there is no limit to how thin you can weld with the oxy-acetylene method.

Mr. W. B. Miller: Twenty to twenty-two gage is plenty thin. We have tried it on some thinner stuff but that work was in a metal that was not ductile after welding. Therefore it was absolutely unfeasible to weld.

Mr. Purves: In mentioning the 20 gage, I should state that it is essential to have the austenitic material and to handle that it is also essential to have a copper backing.

Mr. H. M. Hobart: I should like to know what was the amperage of current?

Mr. Purves: Number fourteen electrode and about 22/25 amperes.

Mr. Chase: I should like to ask Mr. Miller whether gas or oxyacetylene welding is used today in any instance for automatic work where repetitive operations are considerable, where the quantities produced are very large.

Mr. W. B. Miller: It is used in the tube welding machine, if that is automatic. One company is producing tube commercially with an oxyactylene tube welding machine.

Chairman Crowe: A great deal of stainless tube is being welded with the oxyacetylene process.

Mr. W. B. Miller: Brazing was brought up. Our experience has been that it is only feasible to spot braze because you can cover up only a spot or small area with a flux and prevent it from getting a film of oxide.

Chairman Crowe: If there are no other questions, we will consider this session adjourned.

The meeting adjourned at 12.45 o'clock.

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TUESDAY AFTERNOON SESSION

September 23, 1930

The meeting convened at 2.05 o'clock, Mr. F. T. Llewellyn, Past President of the Society, presiding.

Discussion paper "Fatigue Investigation of Welded Joints," by Professor G. E. Thornton.†

Chairman Llewellyn: Professor G. E. Thornton has come all the way from the State College of Washington on the Pacific Coast to tell us what they have been doing out there in research into this most important question.

Those of us who were fortunate enough to hear a preliminary progress report from Professor Thornton a year ago at Cleveland, will appreciate the present opportunity to hear not, perhaps, a final report but a very much fuller report than we had then.

I don't think we can do better than to open the discussion of this paper by inviting Professor H. F. Moore of the University of Illinois to tell us some more about fatigue.

H. F. Moore (University of Illinois): In a general way Professor Thornton's test results are in agreement with the results of the occasional tests of commercial welds sent to the Materials Testing Laboratory of the University of Illinois for determination of the fatigue limit. During the last year there seems to be some improvement in the general run of specimen welds sent to us. Perhaps as good a set of fatigue values as we have ever obtained from welded joints is that reported in Mr. Hodge's paper* in which the fatigue strength of the welded joint under reversed flexure was probably at least 95 per cent of that of the base metal. These joints were machine welded, using a coated welding rod. The fatigue strength of welded joints sent us for test usually ranges from 30 up to 70 per cent of the fatigue strength of the base metal. I agree with Professor Thornton in his list of things detrimental to the strength of a welded joint, and especially with his conclusion that oxide spots are decidedly disastrous. I believe that the presence of a non-oxidizing atmosphere around the weld as it is made is very important.

Concerning the disastrous effect of small oxide spots and blow holes, the theoretical effect is very bad indeed. A very small blow hole or oxide spot would, theoretically, reduce the strength of the joint to one-third its normal value. Actually the reduction of strength is always much less than the theoretical value, because when we consider so small an area as that of a small hole the non-homogeneity of the material becomes a major factor, and the theory of elasticity, which is based on the assumption of homogeneous material, begins to show serious inaccuracies when applied to such metal. As a matter of fact the little holes do not do so much damage as the theory calls for, and Professor Thornton's conclusion, that unless there are enough oxide

†Paper published in the October, 1930, issue, Journal of the A. W. S.
*October, 1930, issue, Journal of the A. W. S.

spots and blow holes to produce a rather widespread effect they are not extremely dangerous, seems sound.

There is one other fact concerning the fatigue strength of welded joints which seems worthy of further emphasis. In many cases welded joints are subjected to repetitions of stress but not to cycles of *reversed* stress. In the case of the base metal, structural steel, the endurance limit under reversed stress is usually a little below the yield point of the steel, but under stress repeated but not reversed, the endurance limit is usually *above* the yield point of the steel and fatigue strength becomes of little importance. In the case of welded joints the yield point is about as high as that of the base metal, but, at the present stage of development, the endurance limit is lower, so that even under stress repeated but not reversed the endurance limit may well be lower than the yield point, and fatigue strength be the determining strength factor.

The most encouraging thing noted in our laboratory is the steady improvement in the fatigue strength of welded joints sent us for test. It is my hope and belief that welded joints with a fatigue strength equal to at least 85 per cent of the fatigue strength of the base metal may become the common thing in the next few years.

Professor C. A. Adams: Mr. Chairman, the question which naturally arises in connection with any set of test results is as to their significance. In other words, where is this ability to withstand fatigue stresses important.

Probably the vast majority of welded joints in service are not subjected to alternating or pulsating stresses of sufficient magnitude and frequency to make the knowledge of their endurance limit important. There are, on the other hand, many very important structures in connection with which the maximum precautions in guarding against failure are necessary. In these cases we cannot afford to take chances. As examples we can cite boiler drums and other pressure vessels where explosions or even leaks will produce disastrous results.

In the case of a steam power boiler no one can say exactly how many times during its life it will be subjected to a pulsation of pressure from the maximum working point to zero or thereabouts. In all probability 100,000 such pulsations would more than cover the life of a power boiler, whereas these endurance limit tests run into millions and tens of millions. Nevertheless, it is important to know the endurance limit of joints in boiler drums since the results of breathing tests on a variety of these drums have shown that defects such as are likely to occur in certain types of welds may cause fatigue failure after as few as 5000 or 6000 applications of a pressure only 50 per cent above the working pressure of the drum, or 30 per cent of the ultimate strength of the plate, and this in spite of the fact that this same welded joint showed a strength under an ordinary single pressure test equal to that of the plate itself. In other words, 5000 applications of a pressure only 30 per cent of the designed strength of the joint caused failure.

Fatigue failure is progressive and starts at some point where the

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stress is concentrated either due to a defect such as a blow hole or slag inclusion, or to the nature of the metal structure; undoubtedly in the case of welds to a variation of this metal structure and a variation in the hardness of adjacent portions causing a concentration of stress. With this evidence before us it would obviously be foolhardy to discount the importance of a knowledge of the fatigue properties of welded joints in the case of important structures where safety is vital.

It is important, therefore, in the case of such critical structures to know that the deposited weld metal and the adjacent base metal are not only thoroughly knit but also as nearly homogeneous as possible. It is also important to know that the weld is free from blow holes or slag inclusions of appreciable size. Fortunately such welds can be and are being made at the present time.

Referring now more specifically to Professor Thornton's paper, his arc welds were all made with bare electrodes and the wide range of endurance limits obtained with these welds is undoubtedly due to the chance of a slag inclusion within the sample The difference in hardness which he notes as between the deposited weld metal and the base metal is undoubtedly a factor in the low average endurance limit obtained in his tests. Incidentally these results are wholly consistent with those obtained, in some cases, many years ago, for bare electrode arc welds.

The superior results obtained by a few manufacturers who employ heavily covered electrodes are due undoubtedly to two causes: First, the welds were made in very heavy plate and were deposited in a large number of layers; when each layer is deposited, the layer below is subject to a heat treatment which refines the grain, and the only layer not subject to this heat treatment is the top layer which is often a reinforcement and afterward machined off. Thus the deposited metal which has shown such high endurance limits, equal in fact to that of the base metal, is in reality a refined metal as far as grain size is concerned, and hardly comparable with the welds tested by Professor Thornton. The second cause is probably due to the employment of electrode covering which provides a highly reducing atmosphere and largely prevents oxide or nitride inclusions It is also possible that the fluxing nature of the electrode covering may result in a less porous deposited metal.

Although it would be unwise to state that such desirable results cannot be obtained with bare electrode welds, it is a significant fact that up to the present time they have not been obtained.

Chairman Llewellyn: We are greatly indebted to Professor Adams for his suggestions and remarks. As I recall the results of this research, a number of the specimens that showed the highest fatigue limit were made by a resistance process, and I am wondering if we may not hear from our resistance friends with regard to that or any other feature they may like to discuss. Would you care to speak on that point, Mr. Woofter?

Mr. H. A. Woofter (Swift Electric Welder Co.): I don't believe I have anything to add at this time, except that it might be interesting

to say that perhaps the best fatigue test is in actual practice, as in connection with truck rims, which have to go over the frozen ground or cobble stones, or automobile rims, which have been run for twelve or fourteen years and have had perhaps millions of severe shocks with many tons of load.

I am just thinking now of some fatigue tests of shafting that had been welded for propellers of ships, which rise out of the water and then go back again in rough seas. We have had those shafts back sometimes two or three times and welded them in new places, but the welds stood while the shaft itself had failed.

It would be wonderfully interesting if we had some way of knowing just what the stresses and strains of these truck wheels, tractor wheels, automobile rims and motor boat shaftings have experienced. Unfortunately, there is no way I can see that they could be even approximated by any fatigue testing machinery we might build.

We did run a series of interesting fatigue tests a few years ago on valve stems for automobiles. The head was made of very fine grained white iron or cast iron to stand the enormous heat of the combustion chamber. The stems were made from 19 per cent chromium and a small percentage of nickel, making a stem that would not rust or stick in the block. We ran some of those under very strong spring tension, several times greater tension than we experience in a truck or automobile, and ran them four and a half million cycles without destruction.

There is no other place where the proof of the pudding is in the eating, so much as in these automobile valve stems jumping off the cams when a car is going at 60 miles per hour, perhaps, and getting a hammer blow of a good many pounds and standing that over a period of years. Very often when an automobile or truck is scrapped it has the original valve stems in it that were placed there when the apparatus was first built. There are a number of cases I can cite where the tests have stood the test of time, and we should really take off our hats to them.

It is regrettable that there has not been more work done along the line of fatigue, but when you estimate that to get absolutely dependable results these tests should be carried on over a period of perhaps years, you can see that it is not feasible for any ordinary manufacturer or any ordinary college to attempt any such standard fatigue tests.

Professor Adams: Mr. Chairman, may I ask if I am correct in understanding that some of the high endurance limit values found by Professor Thornton were on resistance welds?

Professor Thornton: Yes.

Professor Adams: Resistance welds if properly made should be and often are as nearly perfect as you can possibly get, and there is no reason why such a weld, certainly if properly annealed, should not have an endurance limit nearly equal to that of the parent metal. It is, in many respects, analogous to a forged weld, because it is worked mechanically during the cooling period and worked under very considerable pressure, not a hammer blow, but a very high steady pressure which produces the upset.

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Mr. J. J. Crowe: I should like to ask Professor Thornton if, in his opinion, there is any relation between the fatigue strength of the weld metal and the fatigue strength of the welded joint. The point I want to bring out is that you can make a single V weld and you may have weld metal that has as high a fatigue strength, but if in making the joint you don't get complete penetration you may have the notch effect at the bottom of the weld and have a concentration of stresses, and regardless of how high the fatigue limit of your weld metal is, you have a poor joint. Whereas, on the other hand, using a double V joint, welding from both sides with reinforcement, you may have weld metal with a rather low fatigue limit or endurance limit, but due to the reinforcement you may throw your stresses outside of your weld into the parent metal. So it seems to me that in applying the results Professor Thornton has obtained on the fatigue strength of these various weld metals, we should be rather cautious.

Chas. H. Jennings (Westinghouse Elec. & Mfg. Co.): Mr. Thornton has presented in his paper endurance limits for different kinds of welded joints as obtained from small size specimens. The striking point in connection with the endurance limits given is their relatively low value as compared with the parent metal.

The company with which the writer is connected is making an extensive investigation of fatigue of arc welds prepared from low carbon steel plates and electrodes[1,2]. An important development of this investigation is the effect of the test specimen size on the endurance limit obtained[2]. From tests made on specimens ranging from 0.3 in. to 2¼ in. in diameter at the critical section, it has been found that the large size specimens give lower but more consistent results.

From recent tests of 45 deg. double vee butt welds joining low carbon steel plates having an endurance limit of 27,000 lb./sq. in., the endurance limits obtained from 0.3 in. and 2¼ in. diameter specimens were found to be 17,800 lb./sq. in. and 10,000 lb./sq. in., respectively. Although these endurance limits are higher than the value obtained by Mr. Thornton for a 45 deg. double vee weld, they are still much lower than the endurance limit of the parent metal.

The low endurance limit of manually prepared electric and gas welds on low carbon steel must be recognized, but it must not be interpreted to mean that such welds are unsuitable for dynamic purposes. The reliability of a joint depends upon the proper design, and a properly designed welded joint can be made to withstand dynamic loads as well as static loads.

Chairman Llewellyn: I will now ask Professor Thornton to make any reply or further comment that he may care to.

Professor Thornton: In regard to the increments of weight that Mr. Jennings mentioned, if you make those increments of weight too small you would be testing one specimen for several months. We

[1] Fatigue Tests of Fillet Welds, by R. E. Peterson and Chas. H. Jennings, presented before 1930 Annual Meeting of A.S.T.M.

[2] Fatigue and Impact Tests for Welds, by Chas. H. Jennings. Journal of American Welding Society, September, 1930.

took the increment at 2500. We started at 12,500, then 15,000, then 17,500 and up.

I want to impress upon the Society that if we cannot agree on what the endurance limit should be, we should, through our Standards Commitee, agree upon the way in which the specimens should be taken for testing, let it show whatever result it will.

This gets back to what Mr. Crowe said. Say we will take it as a single V. This notch is filled in. Some people take these specimens like this, looking at the plan view, say, across, looking straight down on the deposited metal. They take their fatigue specimen lengthwise in this deposited metal, which will range along the notch in that manner. Then they take fatigue specimens out here in the parent metal which will lie parallel to the notch.

I don't believe that that really gives a true value of that weld in fatigue because you are going to have grain structure here, you are going to have penetration along these areas. If you are going to get a true value of that weld in fatigue you must take it across the notch and not parallel to it.

While I am on my feet I should like to express appreciation for the opportunity of coming to Chicago (we call it East around Washington; you call it West around New York), and being able to present the material which I have. I thank you.

Discussion paper on "The Examination of Welds by the X-Ray Diffraction Method"† by Professor John T. Norton.

Mr. W. M. Dunlap (Aluminum Company of America): I should like to bring out one point. Professor Norton said this was cold rolled material. This was not cold rolled material; it was hot worked.

I might explain some of the symbols he mentioned. It was 2SO. We use the numerals to indicate the composition of the alloys. TS in the case where it is wrought. If no letter follows the numeral it is cast material. S originally used to indicate casting. The next letter indicates the temperature. O indicates carefully annealed, as we say, dead soft. H is hard rolled. This material happens to be what we call hot milled slab, a 2½-in. or 2¾-in. ingot. It is preheated to a temperature of about 975 deg. Fahr. That is pretty high temperature. Aluminum melts at about 1250 deg. It was hot rolled from this ingot down to the ¼-in. plate. In the final pass through the rolls the temperature has dropped to about 750 or 800 deg. It is quite different in structure from the material, which is cold worked. I should like to say further that these are some of the first arc welds I have made, and as then we didn't know much about it, they don't compare to the welds we can make now.

Professor Norton: The actual structure of the weld, speaking of cold work, may be more or less relative, but I was very much surprised to find that the final temperature after passing through the rolls was as high as Mr. Dunlap has indicated. It is an actual fact, however, that a sample of this material taken from the actual plate

†Paper published in the September, 1930, issue, Journal of the A. W. S.

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which he mentions showed the beginning of recrystallization at about 250 deg. C., and it must have been at lower temperature than that.

Mr. Dunlap: From time to time we have taken temperature readings at the final pass. When we roll to three-eights or lighter we always make our tests. Our cold rolling starts at three-eighths. In this case it had no cold rolling at all; it was merely rolled down from the original ingot to ¼ in. It may have been 600 deg. I am satisfied it was not below 600, when our rolls are hot.

Professor Norton: My reference to cold rolling was entirely relative because the sample did not show evidence of recrystallization which is found in really hot rolled material.

Mr. Dunlap: In order to get proper recrystallization in aluminum we have to give the cold work at least 60 per cent reduction in thickness. We do get complete recrystallization on annealing.

I should like to add that the material presented here is no criterion so far as the value of the weld is concerned. It was merely an indication in trying to check up or relate information which is obtained from the x-ray methods with that obtained by ordinary methods of test.

Professor H. F. Moore: I wonder if I may ask Professor Norton one question I have in mind in connection with stress and strain. As I understand it, the x-ray diffraction examination tells the general scheme of atomic arrangement, but it does not tell very much about local distortion from that arrangement. Or, to make the comparison still more crude, the space lattice may be compared to a description of the general arrangement of a regiment of soldiers, telling in how many columns and how many rows they are standing, but not telling how much any one soldier or any one squad of soldiers is out of line. Is this a fairly correct picture?

Professor Norton: The Professor is quite correct in that. However, the x-ray diffraction shows that the intervals are so very sharp and that the alignment of the regiment is very exact, that is, they are well-trained troops. If they are out of line even slightly then these interference maxima become much broader, and if they are seriously out of line we get this asterism, which I spoke of, and it is now possible to study the lack of alignment.

We find that we may consider the number of atoms is so very tremendous that the effect of a single atom out of place or even a few hundred atoms out of place would be extremely small. It is something which is quite beyond our powers of observation by any ordinary method, such as the microscope.

I might add one thing which I completely forgot. The photomicrographs of all these areas were taken, but they showed so little that I did not include them in the slides which I have shown you here. The photomicrographs of the weld metal and the cast metal showed what would be expected and the change of structure as you approached the weld metal was not observable.

Here is a case where the x-rays show something a little bit more than is obtained by the ordinary micrographic methods.

Chairman Llewellyn: Might I ask Professor Norton a question? I have a general impression that the x-ray method [not the diffraction method, but what we call the ordinary method] is one in which you have to examine the original plates if you are going to get any satisfactory results, and that the prints from the plates are not usually satisfactory. Judging from the slides that we have seen, this limitation apparently does not apply to the diffraction method. Am I correct?

Professor Norton: I am afraid you are not because the same limitation applies to these particular slides. These slides are ones I prepared with considerable care. As a matter of fact I am rather proud of them. The same limitation applies. If we are looking for small flaws or cracks or something of that sort we also go back to the original negative, and in these diffraction pictures we are looking for various small traces of asterism, for very small broadening of the spots, indicating local distortion and things of that sort. One again goes back to the original negative. These are prints made from original negatives and then reproduced, so they have a bit less detail.

Discussion paper, "Stress Distribution in Side-Welded Joints"† by Walter H. Weiskopf and Milton Male.

AUTHORS' DISCUSSION
"STRESS DISTRIBUTION IN SIDE-WELDED JOINTS"
By
W. H. Weiskopf and Milton Male

Since the pre-printing of this paper it has been pointed out by Mr. Weiskopf that on Page 46, sheet 2 of Appendix C, Equations (C) and (D) are the general expressions for the direct stress and shear only when the loads are equal on both faces of the bar, which is the condition when there is no eccentricity in the joint.

In order to show very clearly the kind of non-uniform stress distribution that exists, top and side views of half a tension joint under load are presented in Fig. 18 in which the amount of deformation is greatly exaggerated.

To get a complete picture of the stresses in any joint would necessitate a long and tedious series of computations. No designer would think of going through a mathematical solution for every welded problem. What he wants is a rapid and simple means of calculating his critical stresses. Figs. 19 and 20 are offered to fill that need.

The key to the whole problem of shear distribution along welds lies in the effective areas of the members composing the joint. Once these areas are found, only two short slide-rule computations are needed to determine the maximum stress in the weld. Fig. 19 is a chart giving the effective areas in terms of percentages of gross areas for any ratio of $\frac{F}{Z}$. The values in this table were interpolated from the Effective Area curve on page 33 of the printed paper.

†Paper published in September, 1930, issue Journal A. W. S.

Fig. 20 is the companion chart of Fig. 19. These curves immediately give the maximum weld stress when the average stress (usually the design stress) is known. The quantity 3.33 appearing in the constant "b" is the ratio:

$$\frac{\text{Modulus of Elasticity in Tension}}{\text{Detrusion Ratio of Fillet}} = \frac{29{,}000{,}000}{8{,}700{,}000} = 3.33$$

and will be the same for all structural steel joints.

The use of these two charts is all that is required. In the following

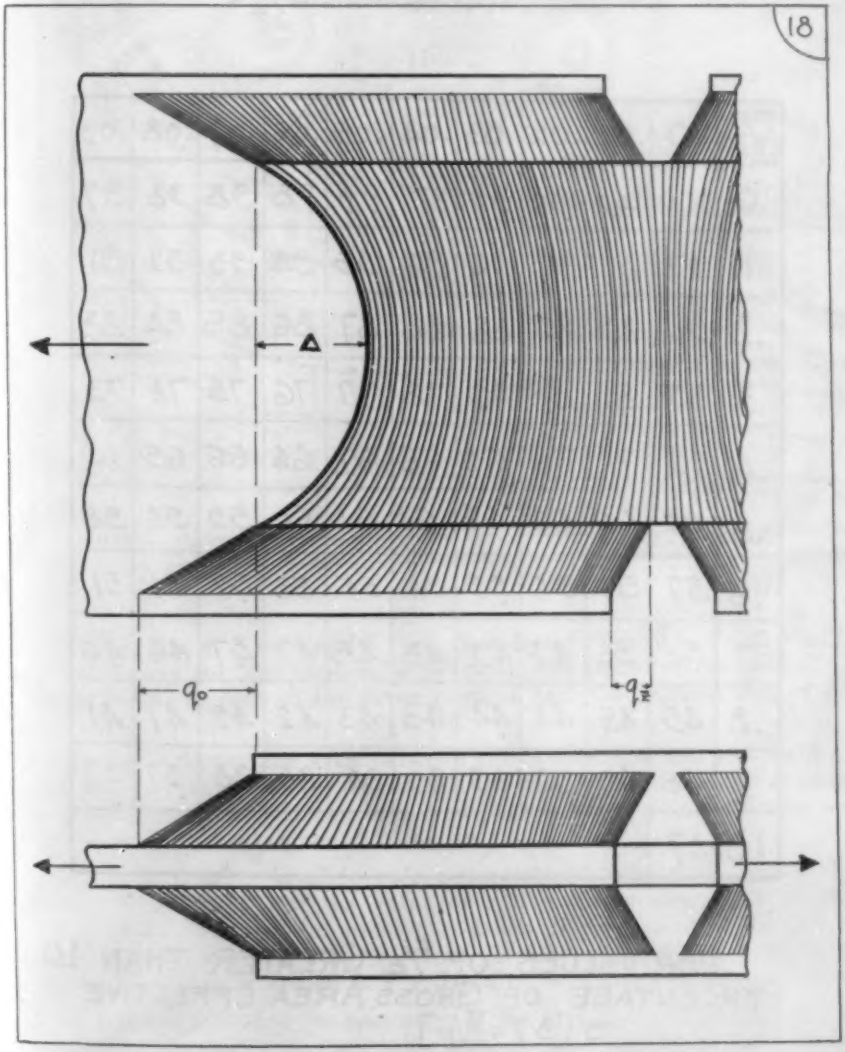


FIG. 18

additional applications of the theory the evaluation of the maximum weld stress in no case took more than 3 minutes.

To clearly illustrate the procedure, the computation for the stress in the welds attaching a seat angle to a column will be discussed in

EFFECTIVE AREA CHART

PERCENTAGE OF GROSS AREA EFFECTIVE FOR ANY VALUE OF F/z.

F/z	0	.01	.02	.03	.04	.05	.06	.07	.08	.09
0	100	100	100	99	99	99	98	98	98	97
.1	97	97	97	96	96	95	94	93	92	91
.2	90	89	89	88	88	87	86	85	84	83
.3	82	81	80	79	78	77	76	75	74	73
.4	72	71	70	69	68	67	66	66	65	65
.5	64	64	63	62	61	61	60	59	58	58
.6	57	57	56	55	54	54	53	52	51	51
.7	50	50	49	49	48	48	47	47	46	46
.8	45	45	44	44	43	43	42	42	41	41
.9	40	40	39	39	39	38	38	38	37	37
1.0	37									

FOR VALUES OF F/z GREATER THAN 1.0 PERCENTAGE OF GROSS AREA EFFECTIVE IS $[37 \times z/F]$.

FIG. 19

the members are supporting the beam.

detail. In Fig. 21, an 8 x 6 x ½ angle, 8 in. long is welded to a 12-in. H-column having a flange 12 x ¾ in. The metal on only one side of the center line will be considered since the angle is disposed symmetrically about this line. It will be remembered that F is the distance from the weld to a line of symmetry or to a line of zero shear. In this case, both the center line and the edge of the flange are lines of zero shear.

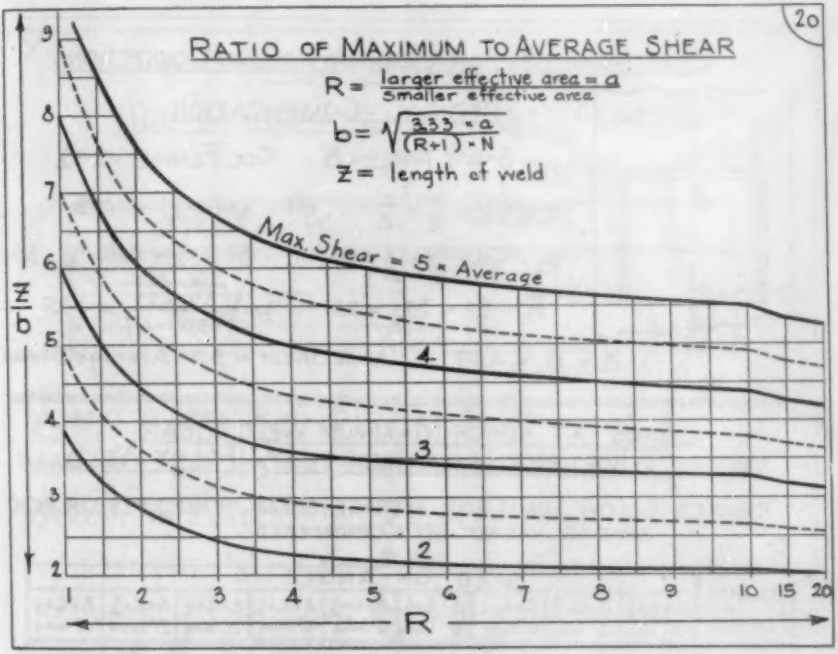


FIG. 20

For the angle, F = 4 and Z = 8, therefore F/Z = 0.5. From Fig. 19, the efficiency for this ratio is 64 per cent, and the effective area of the angle is 64 per cent of the gross area of half the vertical leg, or 1.28 sq. in.

For the column, the area between the center line and the weld has the same efficiency as the angle, but the projecting narrower area has a greater efficiency, 86 per cent, and therefore the total effective area of the flange is, as shown, 3.21 sq. in.

All that follows is slide rule computation. The ratio of the two areas, R = 2.51. For the value of b, the larger area, 3.21 is used, (R + 1) = 3.51, and the number of welds, N, = 1 (since only half the joint is considered). Z/b therefore = 4.57, and with R = 2.51, the maximum stress is shown in Fig. 20 to be 3.3 times the average stress.

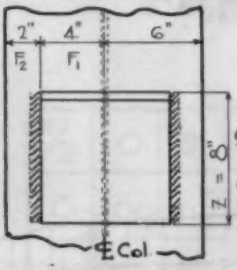
If it is desired that the maximum stress of a ⅜-in. fillet shall not exceed 6000 lb. per inch, then the average stress should be 6000 divided

by 3.3 or 1820, and the load corresponding with that average stress for 16 in. of weld would be 29,100 lb.

In a similar manner the loads were computed for all the combinations given in the table. It cannot be too strongly pointed out that this ratio of twice the maximum to average shear is not a recommendation. What this ratio should be must be determined by experience.

21

SEAT ANGLES FOR BEAM TO COLUMN CONNECTIONS



TYPICAL COMPUTATION

$8\times6\times\frac{1}{2}$ ANGLE $\times$ 8" COL FLANGE $12\times\frac{3}{4}$

a_1 of Angle $= \frac{F_1}{Z} = \frac{4}{8} = .5$, eff. $= .64(4\times\frac{1}{2}) = 1.28$

a_2 of Col. $= \frac{F_2}{Z} = \frac{2}{8} = .25$, eff. $= .86(2\times\frac{3}{4}) + .64(4\times\frac{3}{4}) = 3.21$

$R = \frac{a_2}{a_1} = \frac{3.21}{1.28} = 2.51$ $\quad b = \sqrt{\frac{3.21\times29}{3.51\times1.87}} = 1.75$

$\frac{Z}{b} = \frac{8}{1.75} = 4.57$ $\quad \therefore$ Max Shear $= 3.3 \times$ Average Shear

LOADS AT WHICH MAXIMUM WELD SHEAR WILL BE 6 KIPS PER LINEAR INCH FOR $\frac{3}{8}$" FILLET WELD.

FIGURES BELOW LOADS GIVE AVERAGE SHEAR IN KIPS PER LIN. INCH
BENDING HAS NOT BEEN CONSIDERED

COLUMN FLANGE	SIZE OF ANGLE								
	$6\times4\times\frac{1}{2}$ 6" long	$6\times4\times\frac{3}{4}$ 6" long	$6\times4\times1$ 6" long	$8\times6\times\frac{1}{2}$ 6" long	$8\times6\times\frac{3}{4}$ 6" long	$8\times6\times1$ 6" long	$8\times6\times\frac{1}{2}$ 8" long	$8\times6\times\frac{3}{4}$ 8" long	$8\times6\times1$ 8" long
$8\times\frac{1}{2}$	27.2	36.0	26.9	WIDTH OF OUTSTANDING LEG DOES NOT AFFECT SHEAR DISTRIBUTION BUT MAY AFFECT BENDING					
	2.3	3.0	2.2						
$8\times\frac{3}{4}$	24.8	32.7	40.0						
	2.1	2.7	3.3						
8×1	24.0	31.3	37.0						
	2.0	2.6	3.1						
$12\times\frac{3}{4}$	24.0	27.2	37.0	25.2	34.3	41.7	29.1	37.6	45.7
	2.0	2.3	3.1	1.6	2.1	2.6	1.8	2.4	2.9
$14\times1\frac{3}{4}$	22.1	27.2	36.0	24.3	30.4	34.9	26.7	33.1	38.4
	1.8	2.3	3.0	1.5	1.9	2.2	1.7	2.1	2.4
16×3	22.1	27.2	35.3	24.0	29.5	34.3	25.9	32.0	36.9
	1.8	2.3	2.9	1.5	1.8	2.1	1.6	2.0	2.3

FIG. 21

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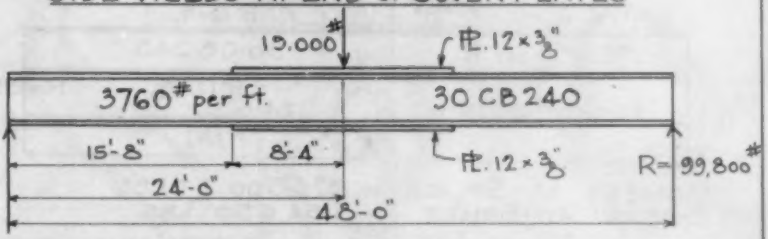
but for the present it is believed that keeping the maximum stress within twice the designed stress is ultra-conservative.

Several interesting facts are brought out in this table. If the angle remains the same, thickening the column flange will increase the maximum stress, thereby decreasing the load. If the flange remains the same, thickening the angle will permit an increase in load. The best possible condition arises when the two effective areas are equal.

22

PLATE GIRDER

SIDE WELDS AT END OF COVER PLATES



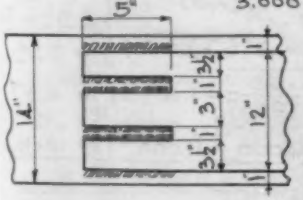
MOMENT AT CENTER = 1,315,000 FT. LBS.

MOMENT AT END OF PLATES = 1,103,000 FT. LBS.

STRESS IN PLATES = $\frac{1103}{1315} \times 18{,}000 = 15{,}100$

$\therefore 15{,}100 \times (12 \times \frac{3}{8}) = 68{,}000\#$ to be developed at end of plate

REQUIRED: $\frac{68{,}000}{3{,}000} = 23$ inches of $\frac{3}{8}$" fillet weld



a_1 for Cover Plate:

$F/z = \frac{1.75}{5} = .35$, eff. $= .77(10 \times \frac{3}{8}) = 2.9$

a_2 for Flange:

Slots: $F/z = \frac{.5}{5} = .1$, eff. $= .97(2) = 1.94$

Edges: $F/z = \frac{1}{5} = .2$, eff. $= .90(2) = 1.80$

Faying: $F/z = \frac{1.75}{5} = .35$, eff. $= .77(10) = 7.70$

$11.44 \times 1.56 = 17.85$

$R = \frac{17.85}{2.9} = 6.16$, $b = \sqrt{\frac{17.85 \times 29}{7.16 \times 6 \times 87}} = 1.18$, $Z/b = 4.25$

MAX. SHEAR = 3.7 × AVERAGE $= 3.7 \times \left[3000 \times \frac{23}{30}\right] = 8{,}500$#/lin. inch

FIG. 22

On a heavy column a thick angle is more efficient than a thin angle, where both have the same size weld.

Several other typical applications of the theory are given (in Figs. 22, 23 and 24), in which welded cover plates and flange and web splices for girders, and a web to chord connection in a truss are analyzed. All the necessary computations are shown and the method for determining the maximum stress in the weld is completely worked out in each case.

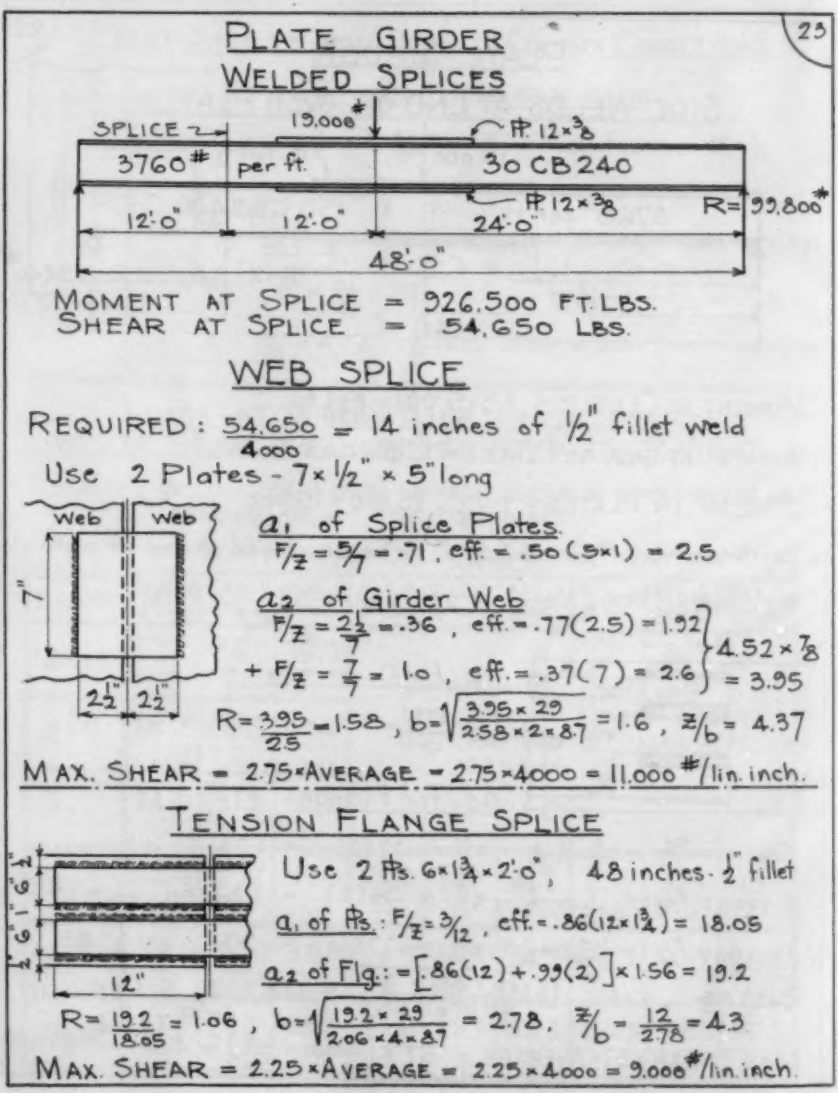

23
PLATE GIRDER
WELDED SPLICES
SPLICE
19,000#
PL 12×3/8
3760# per ft.
30 CB 240
PL 12×3/8
R=99,800#
12'-0"
12'-0"
24'-0"
48'-0"
MOMENT AT SPLICE = 926,500 FT. LBS.
SHEAR AT SPLICE = 54,650 LBS.
WEB SPLICE
REQUIRED: 54,650/4000 = 14 inches of 1/2" fillet weld
Use 2 Plates - 7×1/2" × 5" long
Web
Web
7"
2 1/2"
2 1/2"
a1 of Splice Plates.
F/Z = 5/7 = .71 ; eff. = .50(5×1) = 2.5
a2 of Girder Web
F/Z = 2 1/2/7 = .36 , eff. = .77(2.5) = 1.92
+ F/Z = 7/7 = 1.0 , eff. = .37(7) = 2.6
4.52 × 7/8 = 3.95
R = 3.95/2.5 = 1.58 , b = √(3.95×29 / 2.58×2×8.7) = 1.6 , Z/b = 4.37
MAX. SHEAR = 2.75×AVERAGE = 2.75×4000 = 11,000 #/lin. inch.
TENSION FLANGE SPLICE
2-9"
2-9"
12"
Use 2 Pls. 6×1 3/4×2'-0", 48 inches - 1/2" fillet
a1 of Pls.: F/Z = 3/12 , eff. = .86(12×1 3/4) = 18.05
a2 of Flg.: = [.86(12) + .99(2)] × 1.56 = 19.2
R = 19.2/18.05 = 1.06 , b = √(19.2×29 / 2.06×4×8.7) = 2.78 , Z/b = 12/2.78 = 4.3
MAX. SHEAR = 2.25×AVERAGE = 2.25×4000 = 9,000 #/lin. inch.

FIG. 23

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The matter of determining the effective areas may require some judgment on the part of the designer. The consideration of lines of zero shear should eliminate any uncertainty.

The case frequently arises where the ratio of F/Z exceeds 1, as in the web splice of Fig. 23. For the web, the metal on one side of the weld has a ratio of $\frac{2\frac{1}{2}}{7}$ with efficiency of 77 per cent, but on the other

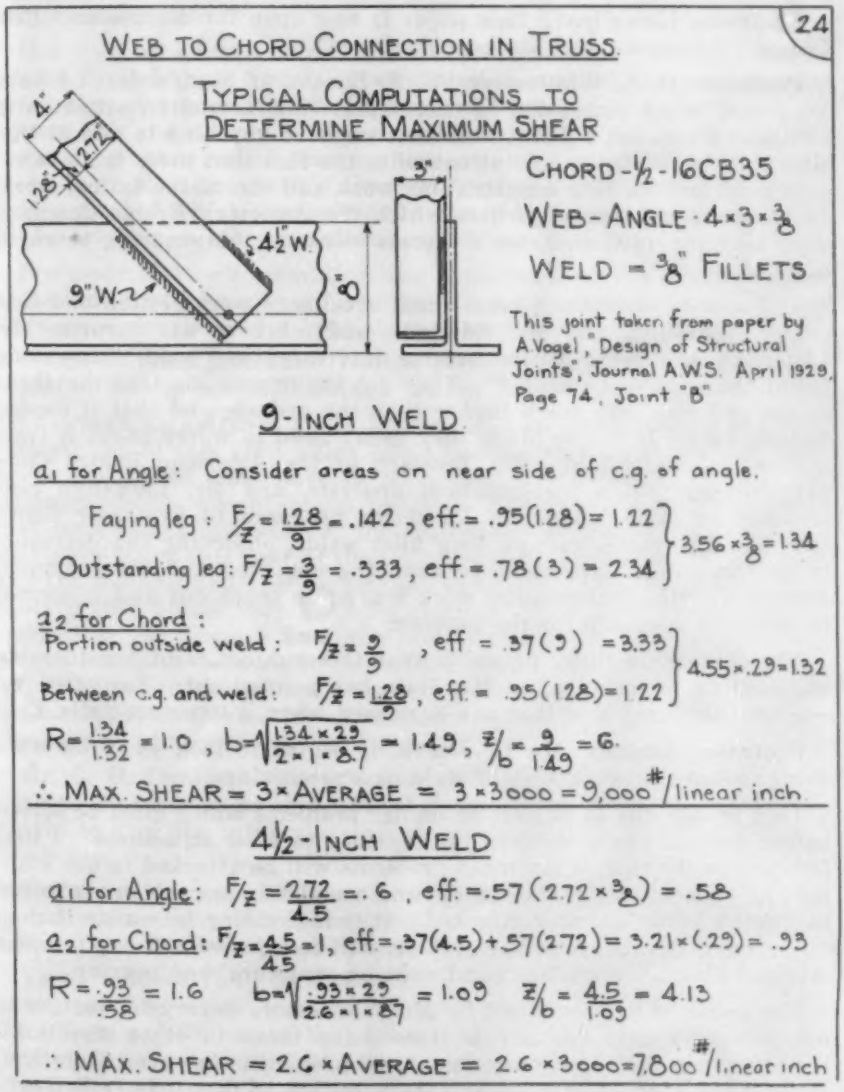
24
WEB TO CHORD CONNECTION IN TRUSS
TYPICAL COMPUTATIONS TO DETERMINE MAXIMUM SHEAR
4"
2.72"
1.28"
9"W.
4½"W.
8"
3"
CHORD - ½ - 16CB35
WEB - ANGLE 4 × 3 × ⅜
WELD = ⅜" FILLETS
This joint taken from paper by A. Vogel, "Design of Structural Joints", Journal A.W.S. April 1929, Page 74, Joint "B"
9-INCH WELD
a1 for Angle: Consider areas on near side of c.g. of angle.
Faying leg: F/Z = 1.28/9 = .142, eff. = .95(1.28) = 1.22
Outstanding leg: F/Z = 3/9 = .333, eff. = .78(3) = 2.34
3.56 × ⅜ = 1.34
a2 for Chord:
Portion outside weld: F/Z = 2/9, eff = .37(9) = 3.33
Between c.g. and weld: F/Z = 1.28/9, eff. = .95(1.28) = 1.22
4.55 × .29 = 1.32
R = 1.34/1.32 = 1.0, b = √(1.34 × 2.9 / 2 × 1 × 8.7) = 1.49, Z/b = 9/1.49 = 6.
∴ MAX. SHEAR = 3 × AVERAGE = 3 × 3000 = 9,000 #/linear inch.
4½-INCH WELD
a1 for Angle: F/Z = 2.72/4.5 = .6, eff. = .57(2.72 × ⅜) = .58
a2 for Chord: F/Z = 4.5/4.5 = 1, eff. = .37(4.5) + .57(2.72) = 3.21 × (.29) = .93
R = .93/.58 = 1.6 b = √(.93 × 2.9 / 2.6 × 1 × 8.7) = 1.09 Z/b = 4.5/1.09 = 4.13
∴ MAX. SHEAR = 2.6 × AVERAGE = 2.6 × 3000 = 7.800 #/linear inch

FIG. 24

side of the weld the width extends to the end of the girder. In such cases the limiting ratio of 1 should be used with an efficiency of 37 per cent. The gross width to be used is then the length of the weld, or 7 in.

Once more the authors wish to point out that the designs illustrated, and the resulting stresses, are not to be considered as recommended practice. They are used merely to show how easily the theory can be adapted to practical design. The question of interpreting the results obtained must be left with the individual designer.

Chairman Llewellyn:. This paper is now open for discussion. Professor Whittemore, may we hear from you?

Professor H. L. Whittemore (U. S. Bureau of Standards): I have been very much interested in this paper. Mr. Llewellyn asked us to comment on it, but I don't think that we have anything to add at this time. I should like to call attention to the fact that there is an interesting history on this experimental work and the mathematical work. In testing some welded girders which the American Bridge Company very kindly contributed, we did some work on the shearing strength of fillet welds.

The results of tests on some small specimens were plotted and sent to Mr. Llewellyn and Mr. Edwards, and much to our surprise Mr. Llewellyn and some others became interested and said, "How long ought the weld to be made?" They got the impression that the shear at the end was very much higher than the average and that it needed looking into. If it was lower they didn't need to worry about it from a practical standpoint. Mr. Troelsch of the American Bridge Company worked out a mathematical analysis, and Mr. Llewellyn contributed valuable help. Mr. Llewellyn proposed to Professor Smith that he make some tests on long fillet welds, observing the detrusion to determine the agreement between the observed and the computed detrusion. His experimental work was quite ingenious and it seemed to me quite adequate for the purpose.

The surprising thing to me is that this subject is of considerable engineering importance, as Mr. Male has pointed out. Too often we neglect the theory and then are surprised when a structure fails.

Professor Adams: Mr. Chairman, it begins to look as if we were going to have a profession of welding engineering.

This is only one of numerous similar problems which must be solved before we can apply welding intelligently to steel structures. I look forward to the time when these problems will be attacked in our engineering schools just as thoroughly and completely as problems involved in riveted joints are now attacked. It is interesting to realize that in all probability this particular problem will be injected not only into our textbooks but also into our handbooks on structural engineering.

The phase of it pointed out by Mr. Whittemore is very interesting to me because I have run across it so many times in other directions. We sometimes look upon our educational preparation as overtheoretical, at least the student often does. As a matter of fact it is rather bru-

tally superficial and most of the careful analytical solutions of engineering problems have been carried out only after some mistakes of a serious nature have forced them upon our attention. It is tremendously pleasing to me that this kind of thing is being done now in the earlier stages so that we will be prepared and ready when the time comes, so that our structural engineers will be able to design their structures intelligently.

I want to express my personal and very hearty appreciation to the authors of this paper, and I think Mr. Male, in his presentation, did a very excellent job.

May I go back just a moment to the previous paper, Mr. Chairman? I think it would be a mistake if we passed it over without some similar expression of appreciation to Professor Norton for bringing to our attention this subject which is new to the majority of this audience, and for making them realize that we have available a method of checking up by more than one method the results of research in this important field, a method which also is bound to be of great practical importance in the solution of other metallurgical problems.

Professor Norton's exposition and explanation is the clearest thing of its kind that I have heard, and I think it brings home to all of us a little more clearly the interpretation of these diffraction pictures.

I wish to thank Professor Norton personally for this work done on behalf of the Bureau of Welding. Thank you. (Applause.)

Chairman Llewellyn: There is one quite important factor in all investigations of this kind which has not been mentioned. Before specimens are tested they have to be prepared and I did not hear the statement made which should be made that both for the specimens that were tested last year at the University of Pittsburgh and those that were tested this year at the University of Pittsburgh, the material and the welding and everything that went with it was furnished by a concern that I hate very much to mention (laughter) because it is a competitor, the Jones & Laughlin Steel Corporation. (Laughter.) Of course I hate it because it is my business to do so. Mr. Danforth, who is connected with that company, is here today, I believe. I think he has followed the testing of these specimens in Pittsburgh. Would you care to add anything, Mr. Danforth?

Mr. G. H. Danforth (Jones & Laughlin Steel Corporation): There are two discussions to this. The first one is this: Years ago I was taught to obey the injunction to love my enemies. That is the reason I love you.

So far as the tests are concerned, I followed them through, but I have nothing here and unfortunately I didn't arrive in the room in time to hear the paper, so I have to ask you to excuse me.

Vice-President F. P. McKibben (General Electric Co.): So far as I know, the first shear tests on side fillets were made in 1922, and I think I am safe in saying that from 1922 to 1930 greater progress has been made in investigating the strength of welded joints than was made in any other type of joint from 1880 to date. (Applause.)

I think we can safely say today that we know as much about fillet welds as we do about rivets.

I can remember back to 1895 when it was clearly shown that on a riveted joint the middle rivets carried very little stress. On the first fillet weld test made in 1922 the same thing appeared to be the case. But we didn't know in 1922 the exact distribution of stress along the fillet. The practicing engineer who is designing and building welded structures owes a great debt to these young men who have so wonderfully worked out these results presented today. The cooperation between the designer and the builder on the one hand and the laboratory investigator on the other leads to wonderful results.

To have prophesied in 1922 that a nineteen-story welded building would be built in 1930 would have classed a man as altogether flighty, but such a building has been completed.

Another point regarding tests: We should be careful in studying tests not to get too close to them. I think if we analyze our problems too closely and look at them too long we get an inferiority complex which makes us hesitate in deciding to do the bold thing. On the other hand, we certainly must be careful not to go beyond the safe limit.

I congratulate Professor Norton and Mr. Male on their wonderful papers.

I have used visual inspection only on welded buildings, but the x-ray process is a wonderful aid in helping to establish the technique of welding.

You gentlemen have offered much help to the practitioner this afternoon.

Mr. Mahoney (McClintic Marshall Company): I refer to your slide showing a cover plate on a girder. The end of the plate has two slots, each 1 in. wide by 5 in. long. Have you analyzed the stresses at the end of the slot adjoining the main portion of the plate?

Mr. Male: In a riveted flange plate, only a small proportion of the area is available for riveting because of required clearances and spacings. For that reason it requires a much greater length of plate to develop the stress in a riveted girder.

Mr. Mahoney: Suppose we draw a line through the end of the slots where the full section begins: perpendicular to the welds, and analyze the plate through this plane. I don't think that the efficiency is very high along this plane.

Mr. Male: The cover plate in this case is 12 in. wide and the slots are 1 in. wide to permit of a ⅜-in. weld on each of the inside surfaces. The strips themselves were 3 in. and 3½ in. The analysis of the plate stress through that section indicates that it is not the critical section. In riveting it is common practice to figure the length to which the cover plate must be extended, and from there on extend it far enough so that enough rivets can be driven to develop the strength of the plate. The increase in length for welded construction on the other

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hand is very much less. We can develop the full strength of that plate in 5 in., where we couldn't do it inside of a foot or a foot and a half with riveted construction. The critical plate section is not at the end of the weld but at the middle of the weld, and the relative efficiencies of the cross-sectional areas of the flange and of the cover plate are computed through the section which remains constant, of course, from one end of the weld to the other. The weld stress, on the other hand, varies from the end of the weld to a minimum somewhere near the center of the weld, the relative cross-sectional areas of the plates determining whether the maximum occurs at the end of the cover plate or at the end of the flange areas in the section. The curve sometimes varies in one way and sometimes it varies in the other way, and if the cross-sectional areas are equal, we get an equal maximum stress at both ends, and the center line of the weld shows the minimum stress.

Mr. Mahoney: Suppose the end of the plate were welded. With this total length of the end weld, the holding power of the side-weld is in excess of the net of this plate by quite an amount, is it not?

Mr. Male: Yes, it is.

Mr. Mahoney: If you had these areas here retained, they would be held by welding, but this plate here wouldn't be worth much, would it?

Mr. Male: The design of plate girders calls for maximum stress at the point of greatest moment. At the end of the weld, the stress in the cover plate is less than the maximum for which the cover plate has been designed, and it has been found in one or two investigations we have made that the critical section for the net plate area at the ends of the weld, where the slots have been made, is sufficient to have the weld develop the strength of the plate.

Mr. Mahoney: I should like to offer a suggestion. Notching out these plates is pretty costly shop fabrication. If you were to make a diagonal cut from each side of the plate to the center, forming a V, it might be possible to have enough length for the welds to develop the plate.

If such a method were followed on your tensile test specimens, what would be the effect on the stress distribution in the welds?

Chairman Llewellyn: That is an interesting point. I believe I could add perhaps one thought regarding your question. While the authors in their slides have indicated slots with fillet welds along each edge, for the reason that this was the only feature investigated, in actual practice, the entire slot would be filled. You would not compute all the filler metal as resisting shear, but you could consider the filler metal as reenforcing the plate.

Mr. Mahoney: You fill up the whole area?

Chairman Llewellyn: Yes.

Mr. Mahoney: Suppose we had several cover plates. Would you set one back and then consider the whole area?

Chairman Llewellyn: Yes, set them back, just as you do in riveted

work. That doesn't quite square with theory, but is, I think, what would be done in practice.

Vice-President McKibben: It is common practice in wind connections of beams to columns to use the triangular shaped plate which the last speaker showed at the left of the blackboard. It is almost a standard for wind connections for the top flange. His objection to the rectangular slot can be overcome by using either a trapezoidal slot or a triangular one, in which case more welding may be secured.

Mr. J. T. Norton: I should like to ask Mr. Male if any work has been done in the examination of these side welds by the photo-elastic method. It seems to me this would offer very excellent means to confirm his theories.

Mr. Male: Several years ago at the Spring Meeting of the Welding Society I showed some slides illustrating the stress distribution in a lap joint, similar to these, except that the cover plate was composed of a single bar instead of two bars. That work, by the way, was done in the M. I. T. laboratory under Professor Frost.

The shear distribution investigated was in the plate along the line of the weld. We had been unable to develop the technique for determining what the stresses in the weld itself were. We determined the stresses in the bar and from that drew conclusions as to what the stress distribution in the weld was. We weren't able to say exactly what the magnitude of the weld stress was. What we were able to do was to draw a general conclusion as to stress distribution in the weld from the stress in the plate. The stress distribution varied greatly with different order of spectra. I recall we had as many as three or four without going beyond the elastic limit of the photo-elastic material we were dealing with. In the grip bar the high concentration of stress was at the end of the weld. The problem is one that might be further investigated, I am sure. Whether or not some such technique has been developed for the examination of stresses in the weld I don't know, but it might prove that the stresses in the bar would form an adequate and reliable index as to the stresses in the weld.

The only variable that we introduced was the eccentricity due to the fact that there was only one cover plate instead of two. In projecting our beam of light through the plate we didn't want any more intereference than we could possibly avoid. That was the reason for having only one cover plate instead of two. The condition, I am sure, would have been considerably improved if we could have removed the eccentricity, but we would have introduced another factor that would have made the investigation itself impossible.

Chairman Llewellyn: I should like to make a few remarks not as chairman of the meeting but as personal comments on some of the papers that have been presented.

In looking at Professor Norton's charts and in going over the mathematical appendix to the paper by Mr. Weiskopf and Mr. Male, I was reminded of the visit that Mr. Einstein made to this country a year or so

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ago, when the newspapers credited him with the statement that there were only a dozen men in the world who could understand the theory of relativity. He never said that. What he said was there were only two and the other one was dead. (Laughter.)

The thing that appealed to me about both of these papers was that in spite of their highbrow aspect, many of the features permit of practical application. I am not qualified to go into that from the standpoint of the x-ray. The thing that appeals in the Weiskopf and Male paper, as has already been stated, is not so much the mathematical investigation [and that is good because it checks], but it is the practical application. What does that practical application tell us?

Mr. Male gave a number of examples based on the supposition that the end shear should not exceed the average shear by more than 100 per cent. He didn't recommend this excess limit. He simply gave examples based on that assumption.

I am going to tell you some facts. Shortly after this paper had been put in manuscript form, I called on a resident engineer of one of the sections of the New York Subway. He showed me a welded joint, almost identical with the joint that was placed on the screen, which had been used in splicing 27 and 30-in. rolled girder beams, which for convenience in construction were used as cantilevers across certain crossframes with the splices placed at overhanging points. They were spliced in a very similar manner to what we just saw on the screen.

I took the detail and asked these young engineers to figure out what the end shear would be in relation to the average. In one case it figured out about five times the average. The joint had been designed on a safety factor of four times. Therefore, you say the joint must have broken. Let's see what happened. These members were temporary beams used as supports for the roadway during construction. They were blasting in the neighborhood of the rock support. An overcharge of dynamite exploded which raised everything in the neighborhood 2 ft., at a time when the roadway was heavily loaded. The welds stood intact, although the steel beam broke two and one-half feet away.

At first blush that seems to throw a doubt on the theory that has been presented. If the theory is right, you will say that if there was a shear of five times what it was figured for, and you had a factor of safety of only four, of course it must have broken. No! This, gentlemen, is just another example of what we have all through applied engineering. All of the theory that has been presented here is based on behavior within the proportional limit, and "there ain't no such animal."

The theory tells what would happen if everything stretched in exact proportion to the load. It doesn't. It doesn't in welding; it doesn't in riveted work; it doesn't in any kind of joint. There are local concentrations on the external surface of a rivet that have never been computed. For many purposes such concentrations can be disregarded; for other purposes they cannot be disregarded.

The value of the study is not so much in the absolute values that it gives as in the simple comparisons it makes possible. You don't need to go through those mathematics. You can apply the chart in two minutes' time to any given problem with the aid of a slide rule. It will tell you the comparative value of this joint as compared to that joint, and that, I think, is its real contribution to the art.

WEDNESDAY MORNING SESSION—Sept. 24, 1930

The meeting convened at 10:15 o'clock, President Doyle presiding.

Discussion of paper on "Resistance Welding of Bar Joints,"† by Frank Burton, Steel Joist Institute.

President Doyle: Gentlemen, you have heard a constructive paper on resistance welding. This is a subject that the American Welding Society is least informed on. We haven't all of the information in the world on either the various types of electric welding or gas welding, but we have less information available on resistance welding than any other kind. For that reason we are looking forward this morning to some very good discussion of Mr. Burton's paper, and we will now declare this meeting open for that discussion.

Mr. G. A. Hughes (Truscon Steel Company): Mr. Chairman and Members of the Welding Society: The manufacturers of flash or butt welders guarantee their welders of being capable to weld a certain number of square inches cross-section area in a given time; also their spot welders of being capable to weld a certain thickness of material, with a given diameter of electrode in a given time. These are maximum capacities, but a manufacturer purchasing a welder will change the clamping devices on flash or butt welders to suit his product and we find all welding equipment operating a large part of the time at reduced capacities and, of course, at reduced efficiencies. Even at maximum capacities the resistance welder is not an efficient electrical machine. The transformer is designed for a very large current and low voltage. The secondary terminals are bolted to the iron of the machine for mechanical strength for the welding clamps (flash welders). The secondary is parallel to iron and partly surrounded by iron.

Therefore, the loss owing to this heavy alternating current paralleling the iron is high. Also all secondary windings of welding transformers are cast copper which does not have the conductivity of hard drawn copper and increases the transformer losses as the I^2R is high. The above is true of all resistance welders, there being at least seven joints or connections in the secondary circuit not counting the joint between the work. This heating of the connections represents power loss and must be charged against the overall efficiency of the welder as the heat is not utilized in the weld.

However, this poor efficiency of the welder is not alarming as a test on a flash welder welding 20 sq. in. showed a consumption of 545 Kw. of energy during the flashing period of 23 seconds. This represents a very low cost per weld.

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†Paper published in the September, 1930, issue Journal of the A. W. S.

In regard to the strength of welds in plates and also in bars. There has been a lot of discussion as to what you might expect when you make a resistance weld in plates, having an electrode above and an electrode below. Just what would be the strength of this weld?

Just before the war the company was interested in making a lot of hospitals for the Russian Government, and some of the material was rejected by the inspectors owing to the fact that some of the welds, while they were pulling out of the lighter plates, which were three-sixteenths of an inch in thickness, still did not develop what the inspectors considered was proper for a resistance weld.

The general manager of the plant thought that inasmuch as these welds were all made on a manually operated machine in the morning when the man was fresh and felt like working, he stepped on the treadle real hard and forced the metal uniformly together and got a good weld; whereas in the evening, when he was getting tired, he was not getting such a good weld because he was not pressing the metal together after heating.

Careful check was made, and we found just the reverse. In the morning when he was fresh and felt like exerting himself the pressure on the lever was the greatest, we had the poorest welding; in the afternoon when he wasn't so brisk with his work, he did not get such a depression in the plates, we obtained better welding.

That led to a lot of investigation as to what would be the proper pressure to be applied for the resistance welding. The result was tabulated in Mr. Burton's paper.

More investigation found that the actual variable that existed and

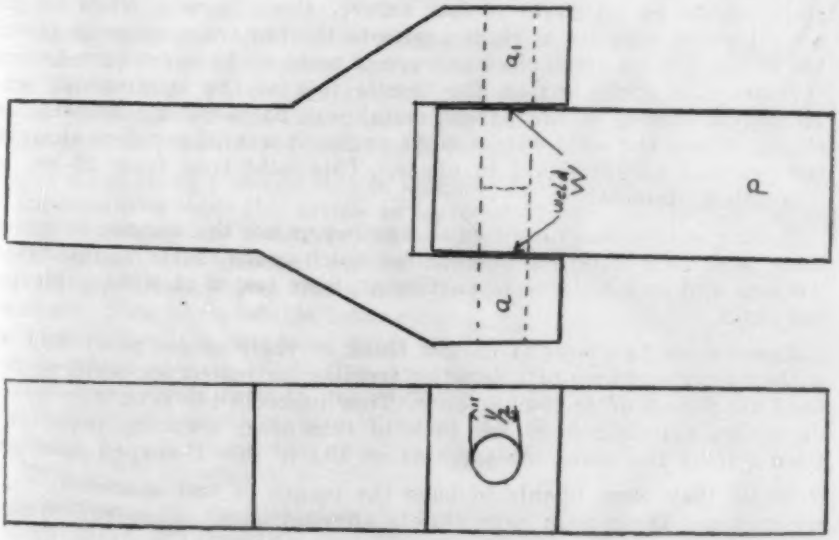

FIG. 1

what you could expect is in the thickness of the plate, which I will designate T, times the periphery of the weld. That metal in shear corresponds to the strength of the weld. When your plate becomes of such thickness that the periphery times the thickness of the metal here is less than the area of the weld, your weld will pull in the form of a cone or it will take that particular form every time, which is the least area here in shear in every case.

Some more investigation was made as to what we could expect as far as the relation of this weld metal to the original parent metal was concerned. The only things we were interested in were structural and intermediate grade steels. Accordingly we made a tool like that shown in Fig. 1, with the plunger P in the middle. Plunger P would very nicely fit on the inside. Then specimens were resistance welded and they were reduced to one-half inch diameter and they were placed, one here, at a and a, with the welding coming right where this plunger meets this U shape, the other coming right in at W. We did that so as to get away from as much of the friction as possible in the machine.

We found in shear, in comparison to the original parent metal, that some of them ran as high as 100 per cent. That did not seem right. Consequently, on some of the tensile resistance butt welded sections we found that some ran over 100 per cent. That didn't seem right. On careful investigation we found that we did not have a weld at right angles, but the weld would come down in an angle as much as 15 deg. Consequently when we put the shear across the weld we were getting part of the parent metal in shear. This weld being, as Mr. Burton stated, harder than the rest of the material, we were running up over 100 per cent, and the same was true in our tensile tests, because we made a test specimen of some welds not being at right angles, on an angle of that nature. Consequently, when we got a weld which was not at right angles to the bar we were getting over 100 per cent. On all of the hundreds of tests we have conducted when they were at right angles, the tensile test of the intermediate and structural grades to the parent metal was 93 per cent; likewise on shear. Where the weld was at right angles it was 93 per cent shear to the original parent metal in shear. This held true from 20 ga. to 3 in. Diam. Rounds.

Some question was raised as to whether or not the manner in which those tests were made was correct, inasmuch as the sheets, in resistance welding and spot welding in particular, were tested at right angles to the grain.

There were two boys (I cannot think of their names now) who as a thesis prepared quite a lengthy treatise on resistance welding for the Case School of Applied Science. They proceeded to take their welds on plates approximately one inch in thickness, reducing them, and then getting the shear the same as we did in this U-shaped machine.

While they were unable to have the length of test specimens that we had, yet their tests very closely checked ours. They ran 91 per cent. (Applause.)

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Mr. Woofter: Mr. Chairman and Gentlemen: I wish to congratulate Mr. Burton on his article on welded steel joists. If we could get more articles from actual users of resistance welding it would do more, I am sure, to enlighten the members of the American Welding Society as well as the public at large regarding the value of resistance welding than any other thing, more than the resistance welding people can do by attending these annual and semi-annual meetings—far more.

I wish to congratulate Mr. Hughes on the investigations he has made, although I believe most of his investigations have been in relation to what we call spot welding.

In looking over the article I think there are a few errors that should be pointed out, for the reason that this JOURNAL is going to practically all the States in the Union and practically all foreign countries, and there are a few things that cannot be considered as accurate.

In my discussion of these points I wish to pay all respects to the author. However, he has investigated only one of the various branches of the art, and only one particular type of apparatus, and, as he says in his article, the resistance welding field is so great that special machines have to be designed for special purposes.

One of the points I should like to bring out concerns page 79. We were sorry Mr. Burton did not state the particular type of welder that was being used wherein the copper and iron loss was 50 per cent of the total energy applied to the apparatus. I do not know of any resistance welding concern making resistance welders who manufacture now quite so bad a machine as that, although twenty-five or thirty years ago some of the welders at that time did have a power factor of only about 37 per cent, and would give about the results that Mr. Burton gets.

I might state that the lighter types of resistance welders, and there are many of them, have power factors up to 80, 81 and 82, and I have seen a few cases where they ran as high as 91, but that is very unusual. You can see that in a piece of apparatus of that kind the iron and copper loss would not begin to be 50 per cent.

One other thing I should like to discuss, lest it might be misleading to someone who reads this article in Japan or Mexico or South America, is that regarding the pressure used to make welds. This is a very wide variable, and also depends on the heating. Mr. Burton says he is getting good welds from using 8000 to 10,000 lb. per square inch of pressure. This is a variable between wide ranges. Mr. Schenck of the Bethlehem Steel Co. gets good welds on 3500 lb. per square inch. Other people using special alloys that are very hard, even when they are hot, in some cases have to use 20,000 lb. per square inch to make a weld. This is especially true in some special alloys used for high pressure boilers where the metal is almost as dense and unyielding when it is hot as when it is cold.

In reference to spot welding, it was not realized until about eight or ten years ago, that all spot welders then in use were not using

enough pressure per square inch to consummate a good weld. They were assuming that the same pressure that would make a good flash or butt weld would be sufficient for a good spot weld.

I believe I can indicate to you very briefly the fallacy of that assumption. It might be true in very thin plates, because in thin plates a very few pounds of pressure will take the buckle out of the sheets and bring them into good juxtaposition for welding. Furthermore, when the electrode pushes and distorts the metal there is very little distortion necessary to push thin plates together.

Let us take thicker plates, perhaps one-half inch thick. This area in here (indicating) is the heated area from which you expect to make your weld. This heated metal is ably supported by the reinforcing effect of the cooler metal here, so that instead of using about 5000 lb. per square inch, as would be used in an ordinary flash or butt weld, it is necessary to use at least 14,000 lb. per square inch in order to start that metal, like a shear or punch, and get a good weld on heavy material. So we could expect, of course, to get very wide differences in pressure, depending upon the particular work to be done.

In spot welding in automobile bodies, where they cannot get to the inside of the body to support it, there is no back-up pressure at all except what the inherent rigidity of the work itself can provide. Suppose the spot weld is being made here. One side of the line is a bar running across a fixture, the other side of the line is fastened to a pry bar. The man fastens himself out here and he make a quick spot without any pressure on the inside of the body at all. Many automobile bodies are made that way. They use this pry bar and you can go along and look inside and see a pretty bright red spot coming through. Incidentally, it is a very pretty thing to watch.

Those are some of the idiosyncrasies of resistance welding, and it shows how hard it is to draw conclusions that will suit more than one particular case. Here is a case where you use practically no pressure. In the case I spoke of with the two one-half inch plates you have to use what seems to be absurdly high pressure.

There is one other thing that might be misconstrued by someone in Japan or Mexico reading the article. Although we know that Mr. Burton referred to the particular transformer he was using, someone who is trying to manufacture transformers for his own use might be misled regarding the cross-section of the secondary. In very small welders the cross-section may not be over ½ in., whereas we have instances where it is as great as 432 sq. in. in cross-section, which is a very powerful machine, of course, and is not very common. But it shows again how widely these particular things vary.

As regards the plain butt weld being the ideal resistance weld, we assume he refers to joists only, but of course that might be misconstrued by people at large. The butt weld is, of course, what we call a spot weld or what we call a mash weld, but so far as rims or rods or bars or wheels or anything of that kind is concerned, less than one per cent of them are being butt welded throughout the world at the present time. In the old days the first welds were done by means

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of straight butt welding for several reasons: First, the flash welding process had not been discovered or generally used until about 1915. Now, however, owing to investigations which have shown that flash welds, when properly made, will develop at least 110 per cent of the strength of the original metal, whereas the butt weld seldom will give more than 90 per cent of the original strength of the metal, that limiting feature would be sufficient, as you can easily see, to cause the use of flash welding. But there are other considerations. It only takes about 40 or 50 per cent as much power to make a flash weld, which is better, than to make a butt weld or a mash weld. This, of course, is another consideration and has great weight.

The two particular types of joists shown are very interesting indeed. Recently in Detroit I saw them being used in a building there. I asked the construction man who goes around over the country installing these joists if he had many failures of welds. He said that in seven years he had never experienced a broken weld, which I think speaks very well for the process, the welding machine, and the particular joists.

One other thing where Mr. Burton errs in his talk here is in regard to the stock being rusty. That has been one of the hardest things we have had to combat for many, many years. It is to get the customer to have his stock come to the welder clean and free from rust. There is no objection to a slight coating of oil. In fact, it is a help in that it keeps the stock from rusting during the time it gets from the punch press or shear, as the case might be, until it comes to the welder.

Contrary to what Mr. Burton has said, they use, in automobile bodies and other products that are bright, shiny, cold rolled steel, a covering, or film, of light oil so that it will not rust while in storage.

As regards automobile rims, the stock is taken in large bundles and put in a pickling tank and then goes to the shear, then rolled, and sent to the welder while it is still warm from the pickling tank, so as to always insure getting clean stock and a good weld. These pickling tanks are costly to buy and install, and take up as much room as the length of this hall with perhaps half its width, with a dozen men operating them. You can easily see that all of the automobile concerns and others would not do all this if it were not absolutely necessary to have bright, clean stock in order to secure good welds at all times.

One other thing I should like to remark about is in connection with welding high carbon steel. We note that the author is using steel as high as 0.654 and does not mention annealing it later. It is a common practice for practically all users of high carbon steel, when the carbon content is above 0.50, to anneal it at all times. Sometimes you can get away with it up to 0.65 or 0.70 without annealing, but you are taking a chance. We have no trouble in welding high carbon steel up as high as 1.20 carbon content, while 0.80 is used every day. It is all flash welded, notwithstanding Mr. Burton's statement that high carbon steel must be butt welded.

Take the case of the Morse Twist Drill Company at New Bedford. You all know what the carbon content must be in those high speed reamers and cutters. They are flash welded onto mild steel shanks and immediately taken from the welder and placed in the annealing oven to neutralize the weld.

In the case of loom flyers, made somewhat like a glorified tuning fork of the old singing school days, the spool of cotton goes on here, and the yarn goes up through these forks. This revolves at an enormously high rate of speed, anywhere from 3500 up to 7000 r.p.m. You can realize the enormous stress from centrifugal force occurring at or about the bend in these arms. There are usually seven welds on these flyers. There are about 400 of these flyers in each loom, and there are sometimes 400 looms in an enormous spinning room. You can imagine what would occur if some of those welds should go bolshevik. They would wreck that plant just as completely as if a bomb had been discharged in it.

They anneal and quench this high carbon weld, which has been flash welded, sometimes as often as seven times, one after another, to get the grain structure as they want it so that it will stand that enormous strain without wrecking the plant and killing the help.

It is very common to flash weld high carbon steels such as are used in rug splitting knives, where the rugs are made and then split into two or more rugs. That has to be extremely high carbon steel, and we have no trouble at all in flash welding, but it must be annealed and quenched, afterward.

As I said before, I am very glad that Mr. Burton has written this article, and I hope that it will be followed by articles from other users of resistance welding. Mr. Spraragen wrote me some time ago for suggestions as to authors for articles on pipe. I suggested that he procure some large maker or user of resistance welded pipe because those fellows have many different angles on it, different from those the manufacturers of the welding machines would have.

The same thing could be very properly done in regard to rims, wheels, and things of that kind.

I don't believe I have anything more, and I hope you will take these suggestions I have made as comments from one who has been in the business for twenty-odd years and not as severe criticism at all. I thank you for your consideration in listening to me. (Applause.)

Professor Adams: First, I wish to support a previous speaker in regretting that we have not had the benefit of more papers and discussions dealing with the problems arising in connection with resistance welding. There is certainly room for work in this field. Moreover, there are many important applications of resistance welding which have never been brought to the attention of the Society, and many places where new applications may yet be made.

Perhaps many of those present do not realize how much resistance welding is now being done. As a matter of fact, the total cross-sec-

tional area of joints welded by this process every day in our industries probably exceeds that of those welded by the arc process.

It may be well at this time to explain briefly the difference between the original Thomson resistance weld and the more modern flash weld.

In the straight resistance weld the two surfaces of the joint to be welded are pressed together and a heavy current passed through the joint. As the resistance of the contact surface is very high, as compared with that of the solid metal, most of the heat is developed at the joint. When the temperature has reached the welding point, further pressure is applied and the weld made.

However, in the case of large surfaces it is difficult to get them to fit so uniformly over the whole area that the distribution of the heat will be sufficiently uniform to produce a good weld.

The flash weld, on the other hand, is made by holding the two surfaces only lightly in contact and allowing the metal to actually burn away until the two surfaces fit perfectly and the heat is uniform over the surfaces. In this process the electrical resistance is much more localized at the joint and the surfaces are raised to a higher temperature, practically to the point of fusion. The upset is then made and soft metal squeezes out around the edge of the joint in a jagged flash, some of which is obviously burned or heavily oxidized on the surface. This flash must then be cleaned off, at least in most cases.

The flash weld requires much less current than the straight resistance weld because of the higher resistance of the loose contact, which sometimes practically constitutes a short arc. For the same reason the heat is more localized in this case.

Referring now specifically to Mr. Burton's paper, it is unfortunate that some of his general discussion of the art, which is undoubtedly injected with the idea of informing the members of the Society on this important subject, applied only to the particular job in hand. I was very glad on this account to hear his oral explanation of this fact, since it would be terrifically misleading to apply this discussion and some of the quantitative values given to the resistance process in general.

As an example, I should like to say a word in regard to the desirability of a rust film on the surface to be welded. In the type of weld presented here by Mr. Burton you have a rounded surface welded on to a flat surface. When the contact is first made its area is small and there is some flash or burning of the metal as it fuses and upsets enough to produce the necessary area of the weld section. In other words, although this weld is made by the straight resistance method, there is some flashing involved. This is shown clearly on the sample exhibited. In such a case, the question of rust or no rust is not important since the pressure in making the weld squeezes out most of the slag which may be present, due either to the original rust film or to the burning incident to the weld. If, on the other hand, you have two relatively large surfaces to be welded together by the straight

resistance push-up method, and if you have a film of oxide over these surfaces, that oxide does not and cannot get out and is highly undesirable in the weld. As a matter of fact, where this type of weld is made between flat surfaces of any considerable dimensions, these surfaces are always carefully cleaned before the weld is made.

Finally, I should like to emphasize again the magnitude of the resistance welding field and to express the hope that we may have more papers and more research work in this important field of welding.

Discussion paper "Cost of Using Welding,"† by R. E. Kinkead, Consulting Engineer.

Mr. Robert E. Kinkead: Mr. Chairman and Gentlemen: In listening to Professor Adams I recalled that years ago Professor Adams predicted that the Welding Society would grow, that the welding industry would grow, and that the Welding Society would serve a useful purpose in publishing the results of various investigators in various and different fields. I want to say that in the last two years the technical data published by the Society have certainly amply justified Professor Adams' prediction.

Mr. E. N. Baldwin (Westinghouse Electric Elevator Company): Mr. Chairman and Members of the Welding Society: The subject of the full economic value of using welding is of vital importance in an industry such as the elevator business because that industry includes not only the manufacture of equipment and its sale, but the installation and the servicing of the equipment.

The following example of a cast iron oil buffer replaced by a welded oil buffer is given:

	Old	Per Cent of Total Cost	New	Per Cent of Total Cost	Savings	Per Cent of Total Saving
Weight	1,174 lb.		174 lb.		1,000 lb.	
Factory Cost		69.2		64.3		67.3
Factory Cost of Mtg.		7.4		5.2		9.8
Oil		1.7		1.7		1.5
Shipping Cost at $0.35 per 100 lb.		2.3		.7		3.6
Trucking Costs		1.2		.9		1.3
Construction Costs at $4.00 per team hr.		18.2		27.2		16.5
Total Value		100.0%		100.0%		100.0%
Costs outside of F. C.		30.8%		35.7%		32.7%

Due to the increased strength of welded steel the buffer can use less material and is smaller in size. Therefore is much less in weight, uses less oil and requires lighter supports.

Due to its less weight, the savings in shipping, trucking and construction costs were made possible. In placing the old buffer in an elevator pit it required a man and his helper to erect a sling and tackle so that the buffer could be lifted into its place; while the new buffer can be lifted in by the constructor and a helper.

The sales value was increased by the following sales points:

1. Less room required in the pit.

†Paper published in September, 1930, issue Journal A. W. S.

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2. Less oil required for maintenance.
3. Due to the light weight of the plunger there is less shock to the passengers in the car when the car strikes the buffer.

From the above table we note that 32.7 per cent of the savings was due to the reduction of weight which directly affected cost other than Manufacturing Cost. One-half of this saving was due to the construction savings.

In order to have true costs an effort should be made to segregate all charges back to the particular apparatus, such as factory costs, construction costs, service and repair costs. Due to the high cost of construction labor it is imperative that construction costs be segregated.

Mr. P. J. Horgan (General Electric Company): The subject of the cost of welding involves two distinct phases of the industry, welding engineering as well as cost accounting. Whether you believe it or not, in spite of what Mr. Kinkead has said, all the office-boy purchasing agents have not disappeared. We still must recognize the fact that we must establish a price on our apparatus, and materials we are trying to weld and sell, and I know of no better indicator than the material, labor and overhead basis. In fact, Mr. Kinkead in his paper very clearly brings that out when in the last paragraph he refers to the fact that the A. O. Smith Corporation have developed such a successful reputation in the marketing of their goods. There is no question in my mind that the typical example he refers to, of the $6,000 vessel, was not made by the A. O. Smith Corporation.

We know that different kinds of work require different qualities, based upon the amount of labor put into getting the result.

To make any discussion of the actual cost of welding as produced by various shops under various conditions would be almost endless detail.

This morning while they were discussing flash welding one thought came to my mind. Among other problems we had in our particular plant was the welding of rings in a single joint. That machine, we will say, of a given size makes rings six and seven inches wide by about three-quarters of an inch thick. We are making those rings today at the rate of about 30 per hour, one every two minutes. It is a machine with 500 kva., and I know Professor Adams has made this statement personally, that we are wasting too much time in flashing. Take that machine producing thirty rings an hour with a corresponding piece-work labor cost. We probably use a minute or a minute and a half in getting the work in and out of the machine, the rest of the time in performing the welding cycle. We will say the machine costs $15,000. Suppose I could take that 30-second welding cycle and cut it down to a 10-second welding cycle. Instead of getting a $15,000 machine we would have to get a $75,000 machine. If we went out to get a $75,000 machine we wouldn't have anything at all. We would still be making those rings in castings.

I say, gentlemen, that the labor reduction due to perhaps increasing

the speed of the welding cycle would have defeated the entire purpose of the job. Therefore, we decided to get the $15,000 machine and establish our piece-work rate on that basis.

I still maintain we must know the quality of the apparatus we are trying to market, and I still believe that for a long, long time to come we must be satisfied with our present cost indicator which is based on material, labor and overhead.

Mr. James W. Owens (Welding Engineering & Research Corporation): Messrs. Horgan and Kinkead are both right. Mr. Horgan is right from the manufacturer's standpoint, for the three factors, labor, material, and overhead, must be taken into consideration; and Mr. Kinkead is right from the purchaser's standpoint, even though the purchaser does not appreciate the fact that "first cost" is frequently a very small percentage of the total or ultimate cost when service over a period of years is considered.

At the present time there is a woeful lack of information on the manufacturing cost of welded products, and recently two instances have come to my attention where bids on welded products varied so widely that the purchaser of the product came to the conclusion that the bidders knew so little about the class of work on which they were bidding that it would be unwise to seriously consider welding.

Fundamentally, there are several causes for this state of affairs, some of which are: Lack of cost data, lack of knowledge of the factors on which costs are based, and planning and scheduling departments functioning under former methods of manufacturing the product.

I have estimated that if welding were fully utilized in a shipyard doing a $20,000,000 business annually, savings would amount to $1,900,000. From this you can see what enormous savings could be effected in industry as a whole if welding were fully applied, instead of the piecemeal method now in vogue in many plants.

WEDNESDAY AFTERNOON SESSION—Sept. 24, 1930

The meeting convened at 2:15 o'clock, Prof. H. L. Whittemore, of the Bureau of Standards, presiding.

Chairman Whittemore: The session this afternoon is a Symposium on Testing of Welds. This is an effort to help the Committee on Standard Tests for Welds in revising its specifications.

Discussion of paper on "Use of Gamma Rays for Examining Welds,"† by Messrs. R. F. Mehl, G. E. Doan and C. S. Barrett.

Mr. Peter F. Alexander (General Electric Company): Mr. Chairman, it is rather difficult to judge the remarkable photographs that Professor Doan obtained by reproduction on the screen. However, if you examine the preprint of that paper where these photographs are reproduced with greater clearness you will see that it is quite possible to obtain very definite outlines of various cavities in steel castings and other structures through thickness of 10 or 12 inches of steel.

†Paper published in the September, 1930, issue Journal of the A. W. S.

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Of course, the fundamental facts underlying the use of gamma rays were known for quite a few years. Professor Rutherford and Soddy used the various methods of detection of gamma rays reported by Professor Doan in their original investigations. However, the results obtained were results of purely scientific research, and were out of reach of engineers and practical metallurgists.

So far as I know there was only one attempt to use gamma rays for the detection of flaws in castings. That attempt was reported about two years ago from Leningrad, in the Soviet Union. Yet even in that investigation only an electrical method of detection of the flaws was used. So this paper and this investigation is really a pioneer work in detection of the flaws in metallurgical structures by means of gamma rays and the photographic plate.

To fully appreciate the novelty and the possibility of this method of testing, we should visualize the wonderful properties of the substance used by Professor Doan. In his investigation he has used not radium but radium emanation. It is a gas evolved by radium. This gas is perfectly neutral, so far as physical and chemical properties are concerned, yet it is extremely radioactive; in fact, it is much more radioactive than radium itself. As Professor Soddy expressed it, one point of radium emanation is equivalent to one-half ton of pure radium. So, due to that extremely high radioactivity of the substance, only infinitesimal amounts of it are necessary. In the work which has been done by Professor Doan probably only a volume equivalent to a pinhead of radium emanation was used. That was sufficient. But we will appreciate still more the radioactivity of this substance if we remember that it is not the gas included in that small capsule which produces the gamma rays. But only the products of the decay of that gas. The gamma rays are produced not by radium emanation but by radium "C," which is deposited like snow on the walls of that glass container from the gas included in that small capsule. Since it is deposited all around on the walls it radiates the gamma rays in all directions. The amount of that deposited radium "C" is so small that it is invisible, yet the radiations issued from that infinitesimal amount of matter are strong enough to penetrate thicknesses of 11 or 12 inches of steel.

It is too early to speculate on the practical results which undoubtedly will follow this pioneer work. Still we may see that Professor Doan showed us a new and powerful method of testing materials which later on could be developed into a practical tool. We can only hope that Professor Doan will continue his work and extend his investigations to other methods of radiography.

For instance, only yesterday we heard a paper on the examination of welds by the monochromatic pinhole method. A beam of X-ray is directed through a thin section of steel and the pattern reproduced on the photographic plate gives us information on the strains and structure of that metal. Unfortunately, the X-rays used in that way are not capable of penetrating more than a few thousandths of an inch in thickness. The sample must be cut out of the weld and ground into

a thin plate. In fact, that process is still a purely laboratory process.

With gamma rays, however, we may penetrate heavy sections of welds and castings and other structures to be examined by this method without destruction of that part of the apparatus, and so obtain the information on the strains and structure of metal in the vital parts of engineering structures.

The cost of radium is extremely high at the present time, somewhere in the neighborhood of $70,000 per gram. However, as Professor Doan pointed out, it is possible to use not pure radium but radium emanation which is evolved continuously and practically indefinitely, regardless of the fact of whether radium is used or not, and without the reduction of the radioactivity of the radium. It is a by-product of radium, so that the cost could be very much lower than that of pure radium.

I hope that this paper will be studied by all the engineers interested in the testing of materials and that it will be an inspiration to other research workers. (Applause.)

Chairman Whittemore: I think Mr. R. W. Clark of the General Electric Company will discuss this paper.

Mr. R. W. Clark: Mr. Alexander has covered the discussion and I have nothing to add.

Chairman Whittemore: I think he did very satisfactorily. Thank you very much, Professor Doan.

Vice-President McKibben: My attention was recently called to the collapse of a double bascule bridge with two arms. While the arms were being raised, four castings, which had been in use fifteen years, broke, and were later found to have shrinkage holes. They were supposed to be of cast steel. When the arms of the bridge fell, the counterweight, weighing 570 tons, dropped into the river and a considerable amount of the machinery and a great deal of structural material of the bridge was destroyed. It cost about $37,000 to repair the damage. If a careful investigation had been made of those four castings by some such process as has been outlined here today and yesterday, the failure of this structure could have been prevented.

Mr. Owens: I would like to ask two questions of Professor Doan. First, does he think the X-raying of six-inch material is commercially practical, and second, does he consider there is enough radium available or in sight to commercially use the gamma rays for heavy material?

Professor Doan: Mr. Owens is asking questions on the application of the method. I think I had better say that we haven't yet built up a table of quantitative data sufficient to say just what thickness of metal requires a certain length of exposure, and a certain intensity of radium source for every possible case. I think anyone familiar with X-Radiography could answer your first question for you. Doctor Kinzel, I am sure, could answer you on the practicability of examining six-inch sections with X-rays, and I think he would say that it isn't practicable at present.

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As to the thickness and the time of exposure required with a given intensity of source, those figures are given for the objects that I showed you on the screen. In these fuller copies of the paper (although I haven't very many of them, you can get all you want from the ASST), is given the exposure time for the different objects, the distance of the object from the radium source, and the intensity of the radium source. There is a great deal of reduction of the time of exposure by using intensifying screens, such as are used in X-ray exposures, of calcium tungstate, the Patterson screen. Of course, the closer you bring your radium source to the object the shorter the time, in accordance with the inverse square law, the number of rays falling on a given area decreasing with the square of the distance. Naturally, since the rays come out radially, the closer the rays are to the object the shorter the time, the stronger the source the shorter the time, and the thinner the object the shorter the time. With those three variables you can make a great many changes to best meet your purpose, keeping in mind that you expose perhaps a dozen objects at one time, distributed as a sphere around the radium source.

Mr. A. B. Zinzel (Union Carbide and Carbon Research Laboratories): It is true that as the X-ray equipment stands now the routine measurement of six-inch material is not economically possible. However, recently million-volt equipment is being considered. We do not know as yet what new fields this will open up. We have not reached the end of the economic possibilities with the X-ray.

Professor Alexander was a little more fortunate than we were in being able to get the Leningrad article. We have been trying to get it.

We were particularly interested to see the present paper, and it certainly deserves commendation.

There seems to be a good deal of enthusiasm among the welders with respect to the possibilities of the X-rays. The method has a great many potentialities. However, we must remember that there may be limiting factors. For example, we were shown here that the rays go through steel about nine times the thickness in the same time as that required in X-rays. That means that the difference in intensity due to a given defect is also diminished. In most of our weld testing we are not interested, in large holes. We are generally interested in the fusion or very small blow-holes. If we go to heavier materials and go to X-rays with the very short wave length, the sensitivity is cut down very seriously. This simply means that this method will have its particular field just as the X-ray has. One is not going to supplant the other, as I see it now. It is rather a case of the methods supplementing each other.

I do want to publicly congratulate the authors on a very fine piece of work. It is an extremely good experimental job and is very much more than just a noble experiment. (Applause.)

Mr. Leon C. Bibber (U. S. Navy): I should like to add that we have given these gentlemen the opportunity of using this thing practically. The U. S. Cruiser Chester, one of the newer cruiser, broke her stern frame, which is a steel casting more than six inches thick in some

places. This break was welded by the metallic arc. We have given the Naval Research Laboratory the opportunity of testing out this process on this break, and if they are successful in making pictures of this very complicated structure we feel that it will be a very good practical test of this new process.

N. Mayhew (Westinghouse Electric & Manufacturing Co.): We had some small gold tubes. I don't remember the metric sizes, but one could get a human hair in the hole, but not a horse hair. The outside diameter was about one-sixty-fourth of an inch. This tube was about five inches long and was filled with radon gas at a quarter atmosphere pressure. The tube was then cut in one-eighth inch lengths, and in cutting the ends were squeezed together, thus forming a small tank about one-eighth inch long by one-sixty-fourth inch diameter. It was found desirable to weld the ends of this tube where the ends were squeezed together. This was done by holding the end of the tube against a carbon block and allowing the current from a condenser to discharge from the tube to the carbon block, thus melting the edges together forming a weld. These tubes of radon gas could be made in lengths up to two feet long. The cost would be less than a radium salt but the life of the gas would be only a few days. This radon gas is made from radium and is radio active, therefore could be used in the inspection of welded seams and joints.

Chairman Whittemore: We should like to get all these suggestions Are you ready to go on with the rest of the program? Professor Doan has another meeting over at the Stevens Hotel and he has asked to be excused. I am sorry he can't stay until the end of the discussion.

Discussion of paper on "Tensile Tests for Welds,"† by Mr. J. W. Owens.

Mr. Owens: Mr. Chairman and Gentlemen: As my paper is brief, my ideas will be better brought to your attention by reading it rather than by simply touching on parts of it. Before reading it, however, I would call your attention to the following typographical errors: On page 80 the sentence "as it is necessary to test welds less than ½ in. thick" should read: "—— less than ¾ in. thick." On page 87, lines two and four, the value 69,700 lb. should be 59,700 lb.; and on page 88, first line, the radius of curvature should be three times the width of the reduced section instead of four times as given. (Mr. Owens then read his prepared paper.)

Mr. Owens: My paper was, of necessity, restricted to the testing of the weld, but as the problem and methods of testing the "filler metal" (welding wire) used to make the weld is practically identical, a few comments on the Society's present specifications for welding wire would be appropriate at this time.

These specifications are primarily based on a chemical analysis of the filler metal and have served a purpose. However, with the introduction of various alloy gas welding rods, coated and covered electrodes, many of which are patented, this type of specification has be-

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come useless as a practical commercial method of selecting and/or purchasing this material. The only practical method then is to specify the physical and other characteristics of the weld metal required and grade or classify all filler metal on this basis, whether it be metal electrodes, gas welding rods or thermit mixtures. For example (considering only perfect specimens) the *minimum* values for carbon steel weld metal deposited with Grade A filler metal might be—T.S.—65,000 lb., Y.P.—50,000 lb.; % elong. in 2 in.—20; % reduction in area—30, specific gravity—7.80; Grade B filler metal—T.S.—60,000 lb., Y.P.—45,000 lb. % elongation in 2 in.—6; % reduction in area—10, specific gravity —7.60, and so on. Gentlemen, such a specification for filler metal will solve many of the problems we are confronted with today. This method of specifying filler metal has been suggested from time to time by Dr. Adams, Mr. McCune, Mr. Spraragen and myself. I believe the time has arrived for this type of filler metal specification, and I hope to see it realized. I thank you. (Applause.)

Chairman Whittemore: I find that I am in hearty agreement with Mr. Owens on most everything. He has given the results of tests upon which he has based his conclusions.

Before we pass on I should like to call attention to his statement about the specimens of a different size, as long as they are four times the diameter and gage length. You remember Past President Sam Miller of this Society, who did so much for welding, used to talk about B. Barba's law. You can take your ½-in. diameter 2-in. gage length A. S. T. M. tensile specimen and divide every dimension by any number you like and make a new drawing. The properties of all these specimens will be the same if the material is the same. We have in an emergency taken specimens ⅛ in. in diameter and ½-in. gage length and obtained the same properties we obtained with larger specimens.

H. F. Moore (University of Illinois): This report on tests, test specimens and test methods is to be commended for its recognition of the various purposes to be served by tests of welded joints: there are tests for studying carefully the uniformity of properties throughout the joint and the base metal, there are tests for strength across the joint—the "practical" test of strengh, there are tests designed to use in testing the skill and reliability of welders. May I emphasize the importance of having suitable tests for welders. We dream of the day when there will be available a simple, inexpensive, practical non-destructive test to determine the soundness of welded joints, but until that day arrives the systematic training of welders in making welds and the systematic testing of their skill from time to time is of major importance.

I may mention one or two minor points about the specimens shown. The round tension specimen described in the A. S. T. M. Tentative Standards is not 0.505 in. diameter. It is ½ in. diameter with a tolerance of ± 0.01 in. That is, any specimen with a diameter between 0.490 and 0.510 in. is acceptable, and the diameter of the specimen should always be measured, never assumed to be 0.505 in. or any other diameter.

The question of proportion of gage length to diameter is covered in the A. S. T. M. Tentative Standards, which definitely state that if a specimen cannot be made so large as ½-in. in diameter, it may be made smaller with a gage length for measuring elongation four times the diameter.

Quite properly Mr. Owens emphasizes the importance of suitable holders (or shackles) for round specimens. The speaker would go even further than Mr. Owens and point out that ordinary spherical seated holders are not always effective when testing brittle material. The form of seat known as the Robertson shackle, and described in the A. S. T. M. Tenative Standards for Tension Tests, is recommended for consideration for such tests.

The tension specimen with the reduced section formed by a circular groove is of interest. The effect of the circular groove is two fold. It increases the irregularity of stress distribution, which tends to weaken the specimen, and restrains the tendency to lateral contraction under tension, which strengthens the specimen. For brittle materials the net effect is to weaken the specimen, and for ductile materials the net effect is usually to increase the tensile strength slightly. It is worthy of note that the uniformity of stress distribution can nearly always be improved by making the specimen longer, with the critical section further removed from the grips.

I believe that the proposed specimen with the "groove," a circle 4 in. in radius, would make a good specimen for testing the strength of the weld as a whole. As the author of the report pointed out, such a specimen would have a tendency to fail in the weld, and with so large a radius as 4 in. the groove would cause very little irregularity in stress distribution.

I believe that the authors of the report have done well to pass lightly over the determination of yield point of welded joint. In a structure the yield point of the *base metal* would be of major importance, because there is so much of it that yielding would tend to cause collapse of the structure. Yielding in the weld metal, however, would affect only a small proportion of the material and would probably mean only a local distortion.

It may be well to point out that none of the proposed tension tests give information as to the strength of the welded joint under the action of stress repeated thousands of times—that is fatigue strength.

Chairman Whittemore: I should like to ask Professor Moore if he agrees with the author of this paper that the 8-in. gage length specimen should be used for ductile materials and the 2-in. gage length specimen for castings and brittle metals?

Professor Moore: With the welded joint in mind?

Chairman Whittemore: No. I think Mr. Owens stated that in the A. S. T. M. specifications the 8-in. gage length specimen is used for ductile material, and the 2-in. for brittle material and castings.

Professor Moore: I do not get that statement.

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Mr. Owens: I made that statement because I happened to look up the A. S. T. M. specifications. Probably you could use either specimens for either material. You don't use the 8-in. for cast or brittle, but you can use the other one for both.

Professor Moore: The other one is used for ductile material, and it is allowable by the A. S. T. M. for material over, I think, 1½ in. thick, to use either specimen.

Chairman Whittemore: It is probably a better specimen than the 8-in. specimen as regards applying the load axially.

Professor Moore: The only objection to the specimen is that you have to have stuff at least ¾ in. in diameter and it costs more for machining.

Mr. Owens: My point is that with ends which can be held in the grips there is no need to thread the ends of the specimen. The cost of the specimen would be reduced and it would be used much more widely.

Professor Moore: The A. S. T. M. allow the use of the threaded ends. The form of ends is not specified.

Chairman Whittemore: I agree with Mr. Owens on that. The cylindrical specimen is probably a better specimen from the testing standpoint. If it is too expensive and you can't get it, that is another story.

Mr. A. B. Kinzel (Union Carbide and Carbon Reasearch Laboratories): I have listened to this paper with very great interest. Mr. Owens has shown very completely how a weld may be analyzed and how a welded structure may be analyzed. The implication is that in routine testing a welded joint should be so analyzed. I don't agree with him there. I should like to quote Mr. S. W. Miller, with whom I was very closely associated. He said more than once that the purpose of the physical tests is to enable us to duplicate materials and those properties of materials in service which we know by experience to have given satisfactory service. That is one purpose. There are others, undoubtedly, but that is the one that we must bear in mind when we are talking about routine and standard tests for welds.

In service the weld is used with the major stress across the weld. It is used as a unit, not as three parts. It is very interesting in a laboratory and as a matter of general study to analyze this unit as Mr. Owens has suggested, but to tell us how that unit is going to serve it seems to me we should test the unit as a whole, and that that should be the standard test.

One of the tests in Mr. Owens' series attempts to do that, but even that has been modified. He has thrown the stress into the weld by the curved section. If we have a parallel section, taken across the weld and tested and it breaks in the base metal, we know that the tensile strength of the welded material and fusion zone is greater than that of the plate, and for engineering purposes that is all we need to know about strength for the structure. Ductility must then be de-

termined. In design the limit stress, which would be the plate stress, is used. If the joint breaks in the weld, then we have only the normal limitations of our testing methods. I say that because of Professor Moore's remarks as to stress distribution, within those limits we have absolute figures as to the ultimate tensile strength of the weld material. We do not have anything quantitative on ductility.

If you are making a tensile test for engineering purposes, there are two things of interest. That is, what is the tensile strength of the weld material, if it isn't as strong as the plate? If it is stronger than the plate, all right. This test should then be used in conjunction with the bend test for ductility, which is an important factor. In the specimens here shown with the curve, as Professor Moore brought out, the final figure is influenced very decidedly. In the Owens specimens the tensile figures are influenced by the ductility. So there, instead of having something which separates the components and different factors, we are getting a specimen which puts the two together. That is another point to be generally considered.

Chairman Whittemore: I have used a lot of those arguments on Mr. Owens, and I am glad to hear others bring them up.

Mr. Owens: If Mr. Kinzel will turn to page 86 he will find that the parallel specimens broke outside the weld and the specimens with the curved reduction at the weld broke in the fusion zone at values which were lower or equivalent to those of the base metal. A parallel specimen does not give you a clear indication of bad fusion. You might have had bad fusion in your specimens with parallel sides and not know it because your weld metal having a higher tensile strength than the base metal, would give you a unit value for the fusion zone metal which is higher than that of the base metal.

Mr. Kinzel: Mr. Chairman, what Mr. Owens says is very true, but he is losing sight of the fact that he is making a tensile test. We are trying to get the tensile strength of the joint and not the quality of the weld in the fusion zone. We get that with other tests.

Mr. Owens: Both should go together.

Mr. H. F. Moore: Mr. Kinzel just made a remark about the length of the specimen. You are going to get the same difficulty with the parallel section if you get a failure in the weld. The weld tries to contract sidewise and is restrained in just the same manner as the other. So the long parallel specimen has no advantage in determining the tensile strength of the weld material.

Mr. Kinzel: That is true, but the supposition must be modified by the fact that all the weld metal in general use that I know of has a higher yield point than the base metal, so the strain action of the base metal, so far as contraction goes, would be very low indeed, if any.

Mr. J. J. Crowe: May I ask Mr. Owens if he has made any studies on that. It seems to me that the test is this: Can you take any one of the test specimens that Mr. Owens has pointed out and from the results of those test specimens evaluate the tensile strength of the joint? It seems to me that what you actually want to know is the

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strength of the joint. Have any of these test specimens given any indication as to what strength you may expect of the welded joint?

There is one other point I should like to bring out. Mr. Owens said that the chemical composition of the weld metal should be the same as that of the parent metal. I think that was something we tried for ten years ago, but more recently very little consideration is given to trying to match the parent metal with the weld metal, and it is not unusual practice to use alloy steels for welding low carbon plates and to use low carbon welding rods to weld alloy plates.

Mr. R. Kraus (Westinghouse Electric & Manufacturing Company): What was that last point on metals?

Chairman Whittemore: I might say, in answer to Mr. Kraus, that I think Mr. Owens said that the base metal and weld meal should be what you are going to use in your structure. They might be the same and they might be different.

Mr. Owens: I said that the ideal weld is one in which the various characteristics of the weld metal and fusion zone are identical or better than those of the base metal. In practice, however, we find that the chemical composition of the weld metal and fusion zone is of less importance than their physical and metallurgical characteristics.

Mr. R. Kraus (Westinghouse Electric & Manufacturing Company): Professor Moore made reference to the testing of welds and the investigations he has conducted. I should like to ask Mr. Owens if he recommends in the testing of welders that the weld be ground flush like the picture shows in his test, or if that is just shown for testing and study of weld metal.

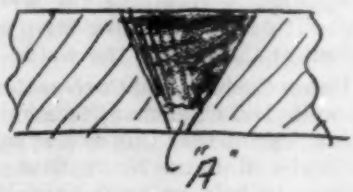

FIG. 1

In the Westinghouse Company we do not let the welder grind anything on his test specimen, because that gives him an opportunity to hide bad work. The moment you allow him to grind the surface, he can chip and reweld at "A", Fig. 1, producing very sound metal you cannot otherwise get in actual work. Therefore, such tests showing high figures are misleading. We enforce the rule that no grinding whatever is permissible on test specimens.

We don't allow him to put on any reinforcement whatever. The specimen must be perfectly flush on both sides and show whatever defects there are, and we grade it on the defects we find on the lower part.

Mr. Owens: You weld with no reinforcement?

Mr. Kraus: No reinforcement. It represents the actual work that we can expect.

Mr. Owens: No, it doesn't, because it is the practice to reinforce a weld to know what values are in here. This value is the true designed value of the section. Then the welder gives a value on which you base your designed value, and the reinforcement is added precaution.

Mr. Kraus: We do not advocate reinforcement of welds. In plate work where conditions permit it, reinforcement is practical sometimes to develop the full value of the plate. However, I am thinking mostly about reinforcement of fillet welds which we do not advocate. With our fillet gage reinforcement involves an expense and does not prove of any value, because it just transfers the weakest section, which is at the throat to the horizontal leg, where the fusion is not as good as at the vertical leg. Our monthly test specimens show that most reinforced welds break at the horizontal leg.

Mr. Owens: In answer to that, I will say that the test specimens were ground for this reason.

Mr. Kraus: A differentiation between the examination of the pure weld metal or the testing of the weld?

Mr. Owens: Suppose fusion and/or the weld metal was defective in a welder's test specimen which was reinforced on one or both sides, and that failure occurred in the base metal because of such reinforcement, would we be any wiser as to the welder's ability to make a sound weld? Therefore, the only way that the efficiency or the proficiency of the welder can be obtained is to test his specimen with the reinforcement removed. In general, it isn't necessary to have a bead or a reinforcement on either side of the weld. However, in practice it is found desirable to, at least, slightly reinforce the weld so as to avoid depressions in the weld. If desired, backing strip can be used instead of a bead or reinforcement at the root of the weld.

Mr. W. B. Miller (Union Carbide and Carbon Research Laboratories): I think it would be well, Mr. Chairman, to mention the fact to those who have not read this reprint that this is a symposium for the benefit of the committee to revise Bulletin No. 1, Standard Tests for Welds. We welcome suggestions to help us come to a satisfactory conclusion as to revising Bulletin No. 1 to suit everybody. We should like all the discussion we can get to that effect. I have a few comments to make on the paper.

First, on page 85 Mr. Owens says, "The notching of a specimen, whether of 'brittle' or 'ductile' material, will give inaccurate results." It has been shown that in notching a ductile material, the concentration of stress is relieved. His results just confirm that thing.

As to this type of specimen, we have done quite a bit of work on reduced sections and have had satisfactory results with an inch parallel section, or say, 1¼ in. to 1½ in. Usually that takes in just the weld metal at the reduced zone ending with about a 2-in. radius. The area between the fillets will include the zone affected by the welding heat, which has a higher yield point than the original plate. Around 99 per cent of the fractures will occur in the weld in the parallel section.

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On Mr. Owens' specimens I suppose that the measurements for the evaluation of the tensile test were taken at the throat or the narrowest section. That was perfectly all right if the break occurred through that section, but Mr. Owens' photographs on page 86 show that the breaks occurred outside, in one case, and diagonally across it in another. The actual thickness where the fractures occurred was not the narrowest section. The result was that he really got a lower tensile strength than his figure denoted.

Chairman Whittemore: How do you do it on ordinary tensile specimens? You look at the fracture—

Mr. Miller: It doesn't show that way on the photographs of fractures. They show a meandering fracture, none of them through the throat or narrow part. I am in favor of reducing sections and hope others will try out both types. It is on all this discussion that the committee has to base what type of specimen it is going to recommend. We find the 1-in. to 1¼-in. parallel section satisfactory. It works well with ordinary plate, say ¼ to ½ or ⅝ in. thick. With this specimen you can measure the thickness, if it breaks anywhere within the measured zone; whereas in the other section, if it breaks outside the narrowest width, which it can very well do, the location and strength will depend on the effect of the welding heat on the base metal. Suppose you used either a gas weld or electric weld with a large heat input. You would have different heat effects on the base metal and therefore would have a different ultimate strength and yield point in the immediately adjacent affected zones.

I wish anyone who is willing to experiment with these different types of tensile specimens would also try out this inch parallel section which we have found to give good results.

Mr. Chas. H. Jennings (Westinghouse Elec. & Mfg. Co.): In line with the reduced-section tensile specimen proposed by Mr. Owens, the writer would like to mention the type of tensile specimen that has been in use at the Westinghouse Research Laboratories for the last few years. A sketch of a ¾-in. specimen is shown in Fig. 1. The features of this specimen are as follows:

1. The weld is located at a reduced section of the specimen, thus causing the fracture to take place in the weld.
2. The radii used in forming the reduced section are large and do not effect the results of the test.
3. The sides of the specimen at the reduced section are parallel to each other for a distance of 1 in.
4. Holes are provided in the ends of the specimen which make it possible to load the specimen by means of pins and thus eliminate as much as possible any secondary bending that may be caused by the loading grips.

The straight portion at the reduced section makes the specimen suitable for obtaining complete tensile data on a welded joint. Huggenberger tensometers with two centimeter gage lengths are very suitable

for obtaining stress strain curves. The use of a small gage length makes it possible to obtain properties of the welded joint without the results being contaminated by the presence of an excessive amount of parent metal.

The straight portion at the critical section makes the specimen suitable for elongation measurements over a 1-in. gage length if an elongation value is desired.

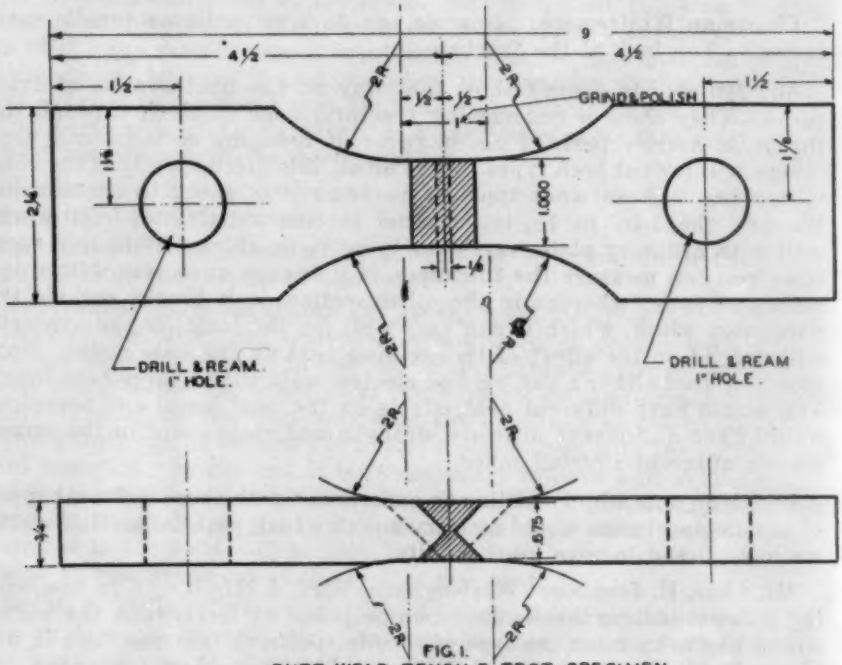

FIG. 1.
BUTT WELD TENSILE TEST SPECIMEN.

The specimen as shown in Fig. 1 is especially adapted for scientific investigations of butt welded joints. If, however, the ultimate strength is the only property desired of the joint, it might be desirable to modify the specimen by changing the ratio of reduced section to maximum section and the method of gripping the specimen in the testing machine. It is highly desirable, however, to retain the 1-in. straight portion at the critical section.

Mr. Owens: Any shape of specimen will have its limitations. The advantages of this one are, however, that it will show whether there is defective fusion or imperfect weld metal; it is easily ground; and localized nicks are avoided when grinding.

Mr. Miller: We can make those inch parallel sections probably more quickly than you could grind out the others because we stack them up in four or five to a group, using a 2-in. radius spiral milling cutter, and 1 in. of travel gives a very quick cut.

The idea is to have discussion and information to help the committee. That's what we are after.

Chairman Whittemore: We will call on Mr. Bussmann of the Standard Steel & Wire Company. (Not present.) We have had quite a little discussion and I think it has been very interesting. Has anybody else anything to contribute?

Mr. Miller: Mr. Chairman, I should have mentioned that the committee has considered the Westinghouse contribution. We are considering all types. I am sorry I didn't mention it so you wouldn't think we were slighting any contribution.

Chairman Whittemore: If anyone has anything to offer on this to the Society or to the Committee on Standard Tests for Welds, we would appreciate it greatly.

Mr. Lincoln: What is the relative tensile strength of steel pulled in the direction of rolling as compared to its tensile strength in a test piece cut at right angles to the direction of rolling?

Mr. Owens: If I follow your analysis, of course I think that the metal should be analogous in both directions rolled. In general I think it would be near enough to take one specimen either one way or the other.

Chairman Whittemore: There isn't very much difference. There is no objection to taking the specimens longitudinally. You showed a transverse specimen without thinking much about it.

Mr. Owens: I don't know what you could do about it. I think you could do both.

Discussion paper on "Bend Tests for Welds"† by Mr. W. B. Miller.

Chairman Whittemore: You see we are taking up these shop tests that are used for testing welders. I had an idea that this subject would not arouse much interest, but apparently you consider them important and are working on the problems involved.

There has been a great deal of discussion of this bend test. Some people say it is fine and some people say it is not. This symposium is an attempt to crystallize this discussion. Mr. Miller has presented an outline of the method. We should like to hear from anybody who has any experience with this bend test.

Mr. Owens: It is true that the bend test shows whether the weld metal is ductile, but I am of the opinion that a tension specimen consisting entirely of weld metal is preferable for accurately determining the ductility of the weld metal deposited by a welding rod or electrode. The particular advantage of the bend test is that it indicates whether good fusion has been obtatined. It might be required in addition to a tension test specimen transverse to the joint.

Mr. Miller: When we first brought this out and recommended it, it seemed to some that we were trying to displace the tensile test. It hasn't been represented that the bend test ductility is the same as tensile ductility. They are two different values and there is no ten-

†Paper published in the October, 1930, issue Journal of the A. W. S.

dency to show that the per cent elongation obtained in the bend test is the same, or greater or less than that obtained in tensile tests of the same material.

Chairman Whittemore: I think that is quite evident, and answers your objection about not being able to get ductility satisfactorily from the tensile test.

Mr. H. F. Moore: I wish to raise the question of the significance of the results of our common tests for ductility—elongation, reduction of area, bend tests of various kinds. If material for drawing or stamping work is being tested then a high degree of stretchability under a single load before a crack occurs is obviously a valuable quality. For steel to be used in a structure an extension of the order of 10 per cent would mean the wrecking of the structure, but a ductility of a few per cent under loads repeated, say, a hundred times is extremely important, since such a degree of ductility allows a readjustment and evening up of stress throughout the member. It is quite probable that the actual *localized* stresses in an actual structural member are quite high, well above the yield point of the metal, involving localized stretches of perhaps ½ of 1 per cent, and thus allowing a readjustment and "evening up" of stress distribution. Do any of the ordinary tests for ductility tell us what we want to know about metal to go into a structure? Or would some test which insured the ability of the metal to stand a moderate number of repetitions of a much smaller stretch be better? I do not know the answers to these questions, but I believe they are worth considering.

Mr. Miller: One of the reasons for ductility is that in ductile material a break is not as violent as in brittle material. That would hark back to the work done in breaking specimens. I should think ductility would be very essential because the work done in breaking any piece of steel is the load times the distance of the travel through. If it has no ductility it doesn't travel through any distance in a violent break. Ductility, I should say, is just as essential in a welded joint as in all these shapes and plates for which the A. S. T. M. has a bend specification, and what we are advocating is a more rational method of evaluating it in terms which are comparable.

Chairman Whittemore: I am quite sure that nobody here will admit that any weld has less than 5 per cent, and according to Professor Moore, they are all right.

Mr. Kinzel: Professor Moore started something. Mr. Miller told you some of the reasons for ductility. There are a few more, one more, anyway. Many of you have seen tests to destruction of pressure vessels, the hydrostatic test. I happen to think of one right now that I happened to witness. I was almost hit by it. The material which in the tensile test had 30 per cent elongation broke with very little elongation. Apparently, it was not a fatigue failure nor anything like it. It was not a notch effect. We have investigated that phase of it pretty carefully. Why did it break short? Because, as I see it, the ductility in a single dimension and the ductility in a three-dimension stretch, such as on the radius of a boiler, are two very different things. Other

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things being equal, we find that the greater the ductility in the single dimensional stress the greater in the three dimensional. But other things are usually factors. You have to know a lot more about your material.

The bend test (and this is partly in answer to what Mr. Owens brought out) as we have specified it, is testing the material in two-dimensional stress at the surface. You don't get failure at the specimen edge. You are testing that material in one more dimension. That is another reason why it differs from the ordinary tensile ductility and why in our estimation it is equally valuable. It is just another thing for a practical consideration. When you are testing the piece in the bend, suppose there should be a minute defect in the weld. In a reasonably ductile material that opens up just a trace at the surface, and the rest of the test is off because the stress decreases as you come down from the surface to the neutral axis. But the test has not been completely vitiated. It has been affected but not completely vitiated by this tiny surface defect. However, in a straight tensile test, if there is a small defect, there is no tendency to relieve the stress or get to an area of lower stress concentration by opening, and you go right to failure with zero elongation. It might not be zero but it will be very, very small and it completely vitiates the test.

While it might be perfectly possible to allow a certain number of tests in a series to be thrown out, when you are testing in this way, because such minute things probably would never bother in service, even under extraordinary fatigue conditions, it seems to me that as a practical test the bend test has very great advantages.

Mr. Owens: Relative to the point raised by Professor Moore about the value of ductility, you will note that in the test given on page 86 that the value was only 10 to 12 per cent, even though the average ultimate strength was 70,050 lb. I know from other tests that this particular weld metal is tough and will resist shock even though the elongation was not of the order of 25 to 30 per cent, which has been generally considered desirable. It might be that further tests of welds made by the various processes will indicate that it might be necessary to revise our opinions as to what constitutes ductility in weld metal.

Mr. Miller: The committee is not interested in what kind of metal we should have in the weld. It is interested in how we should evaluate a bend test.

Chairman Whittemore: The committee may not decide upon any standard bend test. If a bend test is to be included the committee would like to have suggestions as to how this test should be made.

Mr. H. F. Moore: I agree with Mr. Kinzel's statement emphasizing the importance of ductility. It is not infrequently the case that for structural and machine parts ductility is fully as important as strength. The question which puzzles me is this: "Do our ordinary ductility tests, tests which require a large degree of distortion without cracking under a single load, do these tests tell us what we want to know about the serviceability of steel in structures, and for that matter in welds?" Or would some test involving less distortion and involving several

repetitions of load (this would not be a fatigue test involving thousands of loadings) serve better to tell us the serviceability of the metal? As Mr. Kinzel states, the present-day ductility tests—elongation reduction of area, cold-bend tests—are of ancient and honorable standing. But may I point out that the mere age of a standard is no *guarantee* that it is a serviceable standard, for example, for many years it was good medical practice to regard the tomato as a poisonous plant, but that long-established practice did not keep us from changing our views on tomatoes as new evidence came to light.

Mr. Chas. H. Jennings: Weld ductility is of prime importance in welded construction from two standpoints; first, in the process of making certain semi-rigid, rigid and fixed joints a ductile weld deposit is essential in order that the joint may be completed without the weld cracking and that the residual stresses be held to a minimum. Second, in a completed joint, it is essential that the deposited weld metal be ductile in order that it can yield and relieve excessive local stresses which may be present due to inherent design features.

The bend test proposed by Mr. Miller is a method for evaluating the ductility of a completed joint.

The ductility that is essential during the preparation of a joint, however, is a composite quantity consisting of the ductility of the deposited metal at both elevated and normal temperatures and can not be evaluated by a bend test. It might be advisable, therefore, while considering ductility tests to also include a test to cover this phase of the question.

Chairman Whittemore: I can't say that I agree with that. If it is satisfactory when it is put in, the rest is a production problem. Will anyone amplify that in the discussion for the benefit of the committee? The committee really wants to get all the information there is available.

Mr. Owens: Referring to the idea mentioned by Mr. Jennings, a section 8 in. long was V'd out in the center of 1-in. plates approximately 3 ft. square. The V was welded with various types of electrodes. The technic, which included layer deposition and peening, was varied, some of the welds reinforced, and others un-reinforced. Longitudinal and transverse strain gage readings were also taken.

After plates had thoroughly cooled, the welds were given a hammer blow and thermal tests to determine their resistance to residual stresses and shock. For your information, I might say that some of the welds cracked, even though reinforced and regardless of the technic employed; while in others, failure could not be induced, regardless of the test or severity of the hammer blow test. This type of fundamental test can be used to verify the ductility of weld metal obtained with an electrode or gas welding rod. It is also a test of the welder, but is too expensive a test to be used as a general test of welders.

Chairman Whittemore: Do you suggest that we standardize it?

Mr. Owens: I suggest we standardize it?

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Chairman Whittemore: These tests are of no use unless different people in different parts of the world can make the tests and obtain very nearly the same results.

Mr. J. J. Crowe: There is just one point that I should like to make in reference to the bend test, and that is to write in the specifications information as to just what constitutes a failure. Mr. Kinzel pointed out that we get these small or minute failures, sometimes they are a little bit bigger and sometimes they are still larger. Just what are you going to consider your point of failure or the point where you are going to stop the bend?

Chairman Whittemore: There certainly should be something like that. It should be done.

Mr. J. C. Lincoln: It happens that we have done a good deal of work on the ductility of weld metal. We think that ductility of the weld metal is very important. I think the art is growing toward greater ductility. Advances have been made in the last few years. We have succeeded in getting ductility better than that obtained with bare wire. It happens that the tests we have made, hundreds of them, have been all bend tests. Of course our tests have been quite crude. We believe that if we can take a piece of metal and weld it and bend it double we have a better weld than when we can't bend it double. That is about as far as we have gone.

I can say this: It has taken a good many years to get to where we could bend five degrees, and there has been a big advance from the time we could begin to bend it before it broke until we could bend it double. We think pretty well of the bend test because we have used it for many hundreds of tests and we have gotten results from it. We are getting better weld metal.

M. A. S. Wall (Dominion Bridge Company, Ltd.): I haven't very much to say except that it rather seems to me that this will increase the amount of testing we have to do in fabricating shops. It isn't the easiest thing in the world to get as many tests as we want run. A very appreciable amount of expensive labor and time has to be used for them, and I should like to hear of something that would mean the simplification of tests, something that could be done quicker and easier.

Mr. Owens: I do not think so. I think this actually simplifies your testing procedure, for after a thorough analysis of the filler metal, it will be only necessary to make simple tests, for example, bend and tension, to determine the value of the weld. That is why I said in my paper that it was necessary to classify the various kinds of tests for it is first necessary to have complete information on the process, including the weld metal obtained with the process, prior to its use in the making of joints in production.

Chairman Whittemore: Mr. Wall says the vice-president of his company objects to the cost of making the tests. You are proposing that he make more and he doesn't know how he is going to get away with it. They have to be paid for. At least the ones they are making in their shops they have to pay for.

Discussion paper on "Shear Tests for Welds"† by Mr. Andrew Vogel, General Electric Co.

Chairman Whittemore: Mr. Vogel is unable to be here and Mr. R. W. Clark of the General Electric Co. will present the paper.

Mr. Clark read the paper of Mr. Vogel.

Chairman Whittemore: We are certainly very much obliged to Mr. Vogel and to Mr. Clark for presenting this paper.

This is rather a new suggestion, having a bar type specimen, shown here in the reprint on page 74. Do I understand that Mr. Vogel in any way recommends this for a quality test of weld or as a general quality factor, and whether the process is to be used for making butt welds or not?

Mr. Clark. No.

Chairman Whittemore: Only for shear welds?

Mr. R. W. Clark (General Electric Company): For shear welds, particularly in structures, I have one suggestion for a preliminary test in qualifying welders for structural steel welding. It consists of two small plates about ½ in. thick, lap welded together on one edge with about a ½-in. fillet weld. The plates are then wedged apart for inspection of the weld for proper fusion, penetration and porosity. This specimen has been used by the Structural Steel Committee of the American Welding Society as a preliminary test in qualifying welders. We also have used this test extensively in our own plants in qualifying welders and have found it to be very instructive to the welders because it is broken open and inspected in their presence, giving them a chance to see how different conditions affect the inside of a weld. An inexpensive preliminary test also saves considerable money and time when given before allowing a welder to weld specimens which require expensive machining before laboratory testing.

Vice-President McKibben: Mr. Chairman and Gentlemen: On page 74 of the reprint Fig. 9 shows a strap specimen, and before the committee adopts it finally I wish they would consider the following points: The diagram shows four ⅜-in. fillet welds 1½ in. long, but a tolerance of ¼ in. is permitted in the calculation of the average stress along the fillet. If the crater be the normal size in such a fillet it will be nearly ½ in. long, and if the crater is to be included in the 1½-in. fillet, the size of the crater very materially affects the results of the tests. It has been my practice in qualification tests of welders to insist that each man shall fill up the crater, and then we have a fair and uniform basis for comparison between various welders. If this be not done, one welder has 1½ in., including a crater, and another has 1½ in. with the crater filled. One welder might be penalized by reduction and the other welder accepted, when as a matter of fact both may be of equal ability. I think the committee ought to give a little more attention to this detail. Again, I hope the committee will consider, if they haven't already done so, that there are two other methods to determine

†Paper published in the October, 1930, issue Journal of the A. W. S.

the strength of fillets for qualifying welders. Perhaps a compression test with fillets in longitudinal shear might be superior to this tension test for practical considerations.

Again, it may be desirable in qualifying welders to use a compression test with fillets in transverse instead of longitudinal shear. The welder is required to make a fillet of a certain length and the length of the fillet in calculating the average stress is more determinable. I hope the committee will consider these points.

Mr. W. B. Miller: Professor McKibben was speaking about the qualifications for welders. I am glad he recommended that the committee consider his suggestion. I think the paper of Mr. Male and Mr. Weiskopf of yesterday showed that at the end of a side weld, as they would call these, there is a stress concentration, which is all the more reason for filling up those craters. In fact, it should be done in practical work. There is all the reason in the world, from experimental evidence produced yesterday, that craters should be filled up.

On the compression test, didn't Mr. Vogel's work show that the compression shear was 1.3 times the tension shear?

Vice-President McKibben: Larger, yes.

Mr. Miller: I ran across an article recently that was presented to the French Academy by a man named Rosenthal, and he evidently got his cue from Mr. Vogel's article, which was mentioned. He made tests and showed a diagram in which he indicated that the compression shear was the same as the tension. By undercutting the inner member he showed that the difference was due to friction or due to expansion of the specimen under compression. Instead of getting 1.3 he got a 1.04 ratio between compression and tensile. If he had carried the undercutting further, he would probably have gotten even closer. From this the committee could probably say that for figuring compression the same values should be taken as for tension. Those tests show there is no difference.

Vice-President McKibben: Mr. Chairman, we mustn't forget that tests are made for two purposes. One is to ascertain the strength and action of welds for purposes of design; the other is to qualify welders. These are two entirely different matters. I am wondering to just what extent the contraction of the fillet in cooling affects the strength of the fillet. So far as I know this French test is the only one to throw any light on this question. The contraction of rivets in a riveted joint affects the strength of the joint. I think the same thing is going on, to a less extent, in fillet welds.

Mr. Exley (General Electric Co.): I should like to make a suggestion in reference to a combination test for ductility and tension. Most of the tests which have been discussed covered only one kind of stress, either tension or some form of ductile deformation by bending. The tensile stress, of course, is P over A, while the bending stress is MC over I. It seems to me that a combination test specimen covering bending and direct stresses would very largely take care of a test for structural purposes. We have made some tests along this line. I will show the type of specimen which we have used.

What we are all trying to do is to find a test which will be representative of actual service conditions, that is, one involving the ductile qualities of the metal such as eccentricities in the connections producing bending which is to be found in structural work.

In order to get a test representative of that condition the specimen adopted had an eccentricity of ¼ in. off center; otherwise it was the same as a standard specimen for plates.

The first one tested was a plain unwelded specimen of the base metal. The results were that it compared fairly well with the straight specimen of the base metal. In the second test we used an ordinary butt weld finished flush. The test showed very little elongation due to the bending distortion in the weld. By later tests, reinforcing a small amount this way, we were able to increase the resistance at this point and concentrate the stress in the more ductile base metal, making the weld safe for that particular application.

These tests have been written up and will be published in an early issue of the General Electric Review. We shall be glad to submit a copy to any here who may care to have one.

Chairman Whittemore: Then you will get one value and that value would include both the strength and ductility?

Mr. Exley: Yes.

Mr. J. J. Crowe: Would you have the holes in the end to pull by?

Mr. Exley: We used jaw grips in the test described.

Chairman Whittemore: It seems rather evident that the shear test that was proposed would be rather a cheap way to qualify welders. Now here is another specimen that should be considered carefully.

Mr. Exley: This would be the stress-strain curve, we will say, for the plain specimen. For the welded specimen, it would probably go a little higher and look something like that, showing a great reduction in the energy of rupture. After it had been reinforced it compares fairly well with that for the plain plate, showing that it has very similar qualities throughout the full cycle of test.

Chairman Whittemore: Then you have more than one property. You have yield point and you have elongation.

Mr. Exley: We got them all. The curve shows all of the properties.

Chairman Whittemore: You get them all from the straight specimen and these that are offset.

Mr. L. J. Larson (A. O. Smith Corp.): How do you account for the restrained effect at the ends of the specimen?

Mr. Exley: Both the plain specimen and the welded specimen were tested under the same conditions, making the results in this respect at least comparable. However, the end restraint should be taken into account when the stresses are to be determined by formula. The tests described were for classification purposes only.

Chairman Whittemore: Will you write the full details of your specimen to add to this discussion.

Mr. Exley: Yes.

SPECIMEN FOR A RATIONAL DUCTILITY TEST OF WELD METAL

By G. R. Exley, Switchgear Engineering Department, General Electric Company

It is difficult to determine what is a satisfactory amount of ductility in a structural weld, since the conditions in service vary so widely and the irregularities of assembly in a welded structure sometimes introduce important secondary stresses. It is not reasonable to take the ductility as determined by an extreme bending test as a basis, since welded parts are not subjected to such stresses in service. Such materials as rolled steel plates and rivets are subjected to severe bending stresses or deformations in the course of shaping to final dimensions. Welded joints, however, are only made after the material is in its final position, and are, therefore, only subjected to the primary and secondary stresses developed in actual service.

The problem is, therefore, to determine whether the weld material has sufficient ductility to withstand the service stresses, particularly the bending developed as a result of inexact alignment of welded members or unsymmetrical welded joints.

To evaluate the effects of these secondary stresses in a definite way, the eccentric specimens shown in Fig. 8 of the paper have been introduced.[1] They are made by joining two simple plates at a small angle, so that the direct tension on the specimen results in a bending stress which is maximum at the weld. In this particular case, the A. S. T. M. plate specimens 8 in. in gage length were used, with ¼-in. offset at the center of the specimen. The magnitude of the bending stress at the weld will depend upon the amount of the offset.

In the discussion which is to follow, we shall consider the tensile stress as the primary stress, and the bending stresses as the secondary. By relating the offset to the severity of the secondary stresses likely to be found in practice, the conditions of test may be made to approximate service conditions.

When yielding is initiated by a combined stress condition, and the secondary stress must be alleviated by ductile yielding, the extent of the yielding will depend upon the ratio, R, of the secondary (bending) stress to the primary (direct) stress at the elastic limit of the material. The higher this ratio, the greater will be the yield. At this ratio, R, can be predetermined the whole problem of ductility can be put upon a rational basis.

The formula for the maximum combined fiber stress at the center of the specimen, in the case of free ends, or when the end restraint is considered negligible, is as follows:

$$f = f_p + f_s = \frac{P}{A} + \frac{Pe}{S} \qquad (1)$$

in which

f = Combined stress intensity.

[1] Classification and Physical Tests for Various Types of Welded Plate Joints, by G. R. Exley, Journal A. W. S., December, 1930.

f_p = Primary (direct) stress intensity.
f_s = Secondary (bending) stress intensity.
P = Normal direct pull.
e = Eccentricity of specimen with axis of P.
S = Section modulus.
A = Cross-sectional area of specimen.

For rectangular specimens, at the inner edge of the specimen formula (1) becomes:

$$f = \frac{P}{A} + \frac{P}{A} \cdot \frac{6e}{b} \qquad (2)$$

in which b is the width of the specimen. From (2) it is seen that $\frac{6e}{b}$ is the ratio, R, of secondary to primary stress, or

$$R = \frac{6e}{b} \qquad (3)$$

If the ratio R is given, the eccentricity, e, may be determined from (3),

$$e = \frac{Rb}{6} \qquad (4)$$

When the ends of the specimen are subject to end restraint a factor, K, depending upon the amount of restraint involved must be inserted in the right hand members of equations (1), (2), (3) and (4), in which case formula (4) becomes

$$e = \frac{Rb}{6} \cdot K \qquad (5)$$

No account has been taken of the shortening of the bending moment arm, e, due to elastic deflection, as this shortening is small compared with the eccentricity.

When f_s does not exceed f_p the character (tension) of the resultant stress, f, will be the same over the entire section.

As the force is increased, in testing the specimen, ductile yielding sets in at the point of maximum fiber stress and this yielding relieves the secondary stress. After the relief of secondary stress the primary stress (now direct tensile stress) increases until the specimen is ruptured. Stress-strain curves are taken for the whole test and the following are noted:

1. Yield point.
2. Ultimate strength.
3. Energy of rupture.

By comparing the curves taken for a welded and a plain plate specimen of the same dimensions, the quality of the welded joint may be determined with reference to the above properties.

It should be borne in mind when using this type of specimen that a true comparison of the weld metal with the base metal can only be made when both specimens are of uniform section, or say, when the welded specimen is finished flush.

In reinforced joints there are concentrations of stress due to the abrupt change in section, and ultimate rupture may occur outside the weld. However, such joints may still be compared from the standpoint of efficiency by the use of the proposed test specimen.

The special eccentric type of specimen described was developed in connection with a series of classification tests for various types of welded plate joints.[1] As the secondary stress characteristics of the various joints were too complicated for analysis it was felt that a specimen of similar dimensions having a definite secondary stress characteristic would be a valuable asset in comparing the curves for the various types of joints.

In conclusion it may be said that the specimen here proposed for the determination of ductility of welded joints has the advantage of providing a definite test involving the ductile yielding of the metal. Engineering judgment and welding experience must be relied upon to provide estimates of secondary stresses, but when these are estimated a specimen may be made to represent definitely these expected conditions.

APPENDIX

Test Data

The specimens used in connection with this work,[1] were as follows:

PE—1 and 2	Plain plate
WE—1, 2 and 3	Finished butt weld
WE—4	10% reinforced butt weld
WE—5	20% reinforced butt weld

The results for PE — 1 and 2 are:

	PE—1	PE—2
Ultimate strength in lb.	60,000	60,000
Yield point in lb.	33,400	33,400
Energy of rupture in ft. lb.	3,000	2,330

The efficiency of WE — 1, 2 and 3 based on the results of PE & 1 are:

	WE—1	WE—2	WE—3
Ultimate strength	78%	75%	71%
Yield point	100%	100%	100%
Energy of rupture	13%	12%	8%

Showing average losses of 25 per cent in ultimate strength and 89 per cent in energy of rupture.

The efficiency of the reinforced butt welded specimens WE — 4 and 5 based on the results of PE — 1 show a decided improvement due to the added reinforcement:

	WE—4	WE—5
Ultimate strength	110%	110%
Yield point	112%	112%
Energy of rupture	70%	103%

As these specimens were intended for comparative purposes only an arbitrary value of ¼ inch eccentricity was used for all of the specimen which were restrained at the ends by the action of the jaw grips used for holding the specimens.

In connection with the classification tests referred to it is of considerable interest to note the minimum, maximum and average values of the three properties previously mentioned as they compare with those obtained for PE — 1 and 2 and for P — 1 a plain straight specimen of similar dimensions.

EFFICIENCY RATING OF 26 SPECIMENS BASED ON PE—1 AND 2

	Min.	Max.	Average
Ultimate strength	79%	116%	91%
Yield point	99%	145%	109%
Energy of rupture	8%	113%	68%

EFFICIENCY RATING OF 26 SPECIMENS BASED ON P—1

	Min.	Max.	Average
Ultimate strength	88%	124%	101½%
Yield point	92%	137%	101½%
Energy of rupture	8%	80%	46½%

Out of the 26 specimens tested, 3 ruptured at stresses slightly above the yield point. Assuming these three specimens would be disqualified on this account, the remaining 23 specimens compared with PE — 1 and 2 have the following ratings:

EFFICIENCY RATING OF 23 SPECIMENS BASED ON PE—1 AND 2

	Min.	Max.	Average
Ultimate strength	88%	124%	100½%
Yield point	108%	136%	111%
Energy of rupture	43%	112%	75%

Comparing the minimum ultimate strength and yield point obtained for 23 specimens, PE — 1 and 2 and WE — 4 and 5 with the allowable unit working stress of 18,000 lb. per sq. in. for the base metal, the following safety factors are obtained:

	WE—48c5	PE—18c2	23 Specimens
Ultimate strength	3.66	3.33	3.03
Yield point	2.08	1.86	2.12

Comparing the energy of rupture for the three cases with that obtained for a plain straight specimen, the following efficiency ratings are obtained:

	WE—485	PE—18c2	23 Specimens
Efficiency rating	60½%	70%	52%

These final comparisons show a rather close agreement between a series of typical joints such as are to be found in actual practice and specific types of welded and unwelded specimens intended to evaluate welded metal under similar conditions.

The above results which have been taken from a series of classification tests are given here because of the three properties mentioned in connection with the specimen suggested as a standard ductility test specimen.

Mr. Llewellyn: Mr. Chairman, I really hesitate to speak on the subject because I don't know anything about it, never having had experience in laboratory practice. Of course, everybody knows what "drop

of the beam" means. It means you have to make your structure so strong that your beam won't drop. (Laughter.)

One feature in all these sub-topics that I think should be put in the foreground is not only how should the various tests be made, but what is their purpose.

As I take it, the function of this committee is not research; it is not to reflect any doubtful results of recent research. It is rather to crystallize established results and put them in the simplest form suitable to the purpose.

Last evening, by invitation, I was present at a meeting of another major committee of the American Welding Society, the committee that is engaged in drawing up specifications for the qualification of welders. They have pretty near come to definite conclusions, and in those conclusions I noticed that certain tests were to be made, but the form of specimen had to be left blank awaiting the recommendation of the committee on standard tests for welds. In a word, they are waiting for you right now to say just what the form of the specimen should be.

I am going to venture a comment on one or two of the suggestions made. The one suggested by Mr. Exler seems to me very admirable in theory. I do not think it would work so well in practice for the very reason that has been adduced in its favor, namely, that it involves too many variables. A very slight difference in the amount of eccentricity will affect the results very much more than the angle of difference. The increase is very, very rapid.

It seems to me the committee should concentrate on the simplest possible tension specimen that will serve the purpose, and, as I take it, that purpose is not to cover the requirements of special industries but to cover general requirements that are not otherwise covered. Therefore, it should be as simple and as inexpensive as possible.

Whether or not the results shown by the test are an accurate reflection of true tension, I don't care, and I don't think you care. If the results show a strength that is less than that of the well, good, it doesn't much matter.

This is not a committee on high research, so I think the test should be as simple as possible, and as far as possible should follow the lines of established practice. I am not prepared to intimate whether or not the parallel sided test specimen now called for by the A. S. T. M., is suitable. If it is pretty near suitable, I would urge that this committee adopt it; if it is not pretty near suitable, why, of course, that is another matter.

Similarly with the bend test. I don't think it matters much whether the bend test reflects the same measure of ductility that might be brought out in a more accurate test. If it is useful for comparative purposes I think it would serve every purpose.

There are two things that I would urge, namely, first, consider in connection with every test how it is going to be used. What is its purpose? Secondly, make it as simple as possible rather than along the lines of some unestablished even though promising new research.

Knowing nothing about the subject and therefore being thoroughly well qualified to speak on it, I am going to qualify as Thomas Carlyle did. You know he said that the greatest writer was the man who wrote nothing, and he proved it in forty-nine volumes. I am going to lay claim to highest oratory by now remaining heroically silent. (Laughter and applause.)

Chairman Whittemore: I think that is a pretty good summary of the things we ought to consider.

Mr. Owens: It is my understanding that the program of the committee involves the standardization of tests and test specimens for qualifying welders; comparing filler metal; comparing processes, etc.

Chairman Whittemore: It is perfectly true, as Mr. Llewellyn pointed out, people make tests for different reasons. There should be a statement at the beginning of each description of a test indicating what information should be expected from the test.

Mr. Owens: My viewpoint is that the committee has to consider the various uses to which the specimens will be put, and that neither the tests nor test specimens can be restricted to the testing of welders. In view of this, I differ with Mr. Llewellyn.

Professor McKibben's suggestion of a compression specimen for testing fillet welds in shear appears a good one. However, if the fillet weld is placed so that it is in normal shear, failure will occur along the fusion plane, whereas if it is placed so that it is in parallel shear or in the direction of stress, failure will occur through the throat. I tried to use the shear specimen suggested by the committee and found that it is not only expensive but that its width at its ends had to be reduced from 3 to 2½ in. in order to permit insertion in the jaws of our tension testing machine.

Vice-President McKibben: Mr. Chairman, I am not advocating the entire elimination of the old tension strap test but I do think the committee ought to consider the matter of testing these under compression.

Mr. Bibber: I am certainly pleased to hear Professor McKibben say that the plane of failure was through the throat. Mathematically, it appeared that such would be the case and a series of experiments was outlined to demonstrate this point. We had a series of specimens made up, ranging from 1/16 in. to 1¼ in. in size. We tested them in compression and hopefully watched for them to fail at the throat, but they did not do so. They ruptured along the parallel leg S′V′ as is shown in figure (1). Everyone tried to fail through the throat S′H″ and one actually did rupture at an angle of about 30 deg. The failure to follow the theory, however, was not the fault of the theory, it was due to the fact that you cannot duplicate the theoretical conditions in a testing machine.

From figure (1) it can be seen that the force "P" is balanced by the other two forces $\frac{P}{2}$ but that the couple $\frac{P}{2} \times T$ is not balanced, and the only thing that can balance it is the bending in the weld. The speci-

mens soon take the shape as shown by the dotted lines and failure is a progressive tearing off of the side members, that is, ultimate failure is due to combined tension and shear. This is further supported by

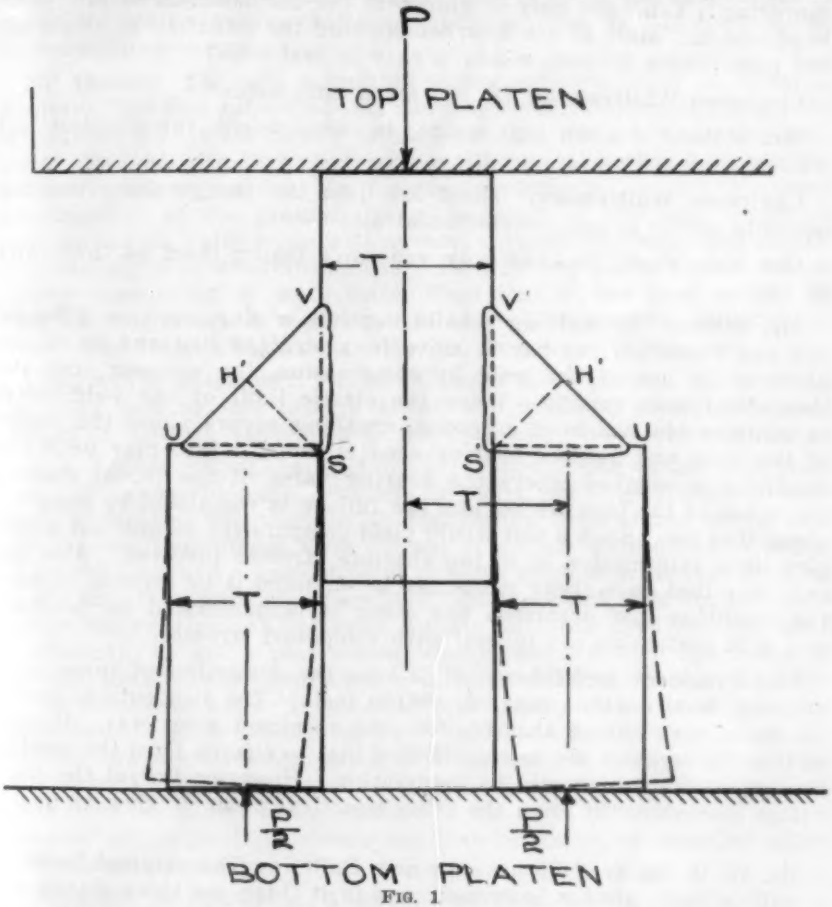

FIG. 1

the fact that the average stress at failure was about 30,000 pounds per square inch, whereas, the shearing value of the corresponding welding, determined from torsion experiments, was in the neighborhood of 47,000 pounds per square inch.

Mr. Bibber: The length of specimen has an influence on the tendency of specimen to spread and the friction of the specimen on the bottom platen also influences the result and the presence of a flaw at the root of a weld would be much more harmful than would be the case with a straight tension test. The first two factors have no bearing on a tension test, and the presence of a flaw in such a test would merely reduce the average value slightly. Furthermore, on the grounds of simplicity, it would seem that the tension test is the easiest method of testing.

In connection with the parallel shear weld, if we are striving for simplicity, why go to the parallel shear weld which has one of the most complicated stress conditions of anything we know about in engineering? You have only to glance at the mathematics of Mr. Weiskopf and Mr. Male to see how complicated the situation is. Why not use pure simple tension, which is easy to deal with?

Chairman Whittemore: Do you mean butt welds?

Mr. Bibber: I mean butt welds; in other words, the simplest test we can work with.

Chairman Whittemore: These are just the things the committee needs to arrive at any conclusion at all.

One man wants to know why you can't fasten them so they can't fly out.

Mr. Bibber: By welding a solid bar into a ring, such as a flange, you can constrain the bar to move in a straight line and up to the point of failure of the weld by compression, the stresses obey the theoretical laws exactly. When the elastic limit of the weld metal in compression has been exceeded, crushing occurs along the throat of the weld and greater bearing area is brought into play until the condition is reached where the bearing value of the throat exceeds the value of the parallel leg and the failure is completed by shearing along that leg. Such a test would yield comparative values, but would give little information as to the absolute stresses involved. Also the only way that pure shear stress can be obtained is by torsion. Under the condition just described the shear is contaminated by bending, and it is preferable not to deal with compound stresses.

Vice-President McKibben: It is true the distortion of those compression tests exceeds that of tension tests. The two outside plates assume a very curved shape before the specimen gives way. It may be that the stresses are so complicated that to change from the tension to compression test would be inadvisable. However, I want the committee to consider it from the other practical point of view of qualifying welders.

Mr. W. B. Miller: We have no new Bulletin. The original Bulletin is still in force until it is revised, and in it there are three standards, shop, commercial, and research. These may be continued. If it is just a shop test, there will be a certain specimen which will cover Mr. Llewellyn's recommendations. If it is research, we can have more of these elaborately prepared specimens which have been discussed.

Chairman Whittemore: You are right about that.

Well, if there is no more discussion on this we will take up the last paper. It is about twenty minutes past five, but we will have another three-quarters of an hour or so.

Discussion paper "Fatigue and Impact Tests for Welds,"† by Mr. C. H. Jennings.

Chairman Whittemore: I certainly take off my hat to the commer-

†Paper published in the September, 1930, issue Journal of the A. W. S.

cial organization that will report a product which has such low endurance limits. I should think they would be afraid to publish the data. Discussion of such data leads to the development of methods of obtaining welds having better properties, and is of great value to the welding industry.

Mr. Owens: The data submitted in the author's paper is of value. However, like that submitted this morning by Mr. Burton they might be misleading if it is not clearly pointed out that the values are for weld metal obtained with bare electrodes or filler metal having a high nitrogen and oxygen content. As I recently conducted a very thorough investigation of the pressure vessel industry, I was able to obtain information on welds made with several covered electrodes and special gas welding rods wherein ductility, fatigue, impact and other values closely approached or were better than that of the base metal. In view of this, please do not conclude that all weld metal has the low impact and fatigue values given by Mr. Jennings. (Applause.)

Chairman Whittemore: I think it ought to be pointed out that Mr. Jennings said he was talking about test methods, giving you some results of his own experiments. He said they were only tentative.

L. J. Larson (A. O. Smith Corp.): I should like to ask one question. If I understood Mr. Jennings correctly, the large specimens were made by welding together the 45 deg. conical ends of two round bars and the small specimens were cut out of a plate welded flat. Welding in a groove around a conical point is much more difficult than welding in the flat. It is probable, therefore, that the welds used for the large specimens were not of the same quality as those used for the small specimens. To get a real comparison between welded specimens of various sizes all the specimens should be cut from welds in plates of the same thickness. It is not safe to assume that a weld in a thin plate has the same properties as a weld in a heavy plate. For this purpose the stock selected must be thick enough to make the largest specimens and the small specimens must be taken from various locations from the center to the surface of the weld. The average results obtained on the small specimens can then be compared with the results of the large specimens.

Mr. Chas. H. Jennings (Westinghouse Elec. & Mfg. Co.): There is undoubtedly an added variable introduced in the 2¼-in. diameter test specimen by preparing the blanks from round bars with cone-shaped ends rather than preparing them from plates with the corresponding rectangular-shaped ends. This added variable does not seem to affect the results, however, because tests have been made on specimens prepared from plates, and the results obtained were in good agreement with the results obtained from the specimens prepared from round bars.

It is important to strongly emphasize the following point in regard to the impact values obtained for arc welds made with bare low-carbon electrodes. The fact that the impact values obtained are low does not imply that such welds are unsatisfactory for use on structures subject to shock. As mentioned in the paper, the suitability of a structure to withstand shock depends upon the use of proper materials and good design.

Mr. H. F. Moore: The fatigue specimen shown, a rotating-beam specimen, is a very good one, but rather expensive. In the Materials Testing Laboratory of the University of Illinois we have had quite good success in using a flat specimen, much like the proposed tension specimen, bent back and forth by a cam, with the load measured by the deflection of an elastic spring. With such a rig it is possible to test plates of considerable thickness, and the specimens are comparatively inexpensive.

Chairman Whittemore: Well, if there is nothing more which should be presented at this meeting we will adjourn. Please remember that Mr. Farmer, chairman of the Committee on Standard Tests for Welds, couldn't come.

(The meeting adjourned at 5:55 o'clock.)

THURSDAY AFTERNOON SESSION

September 25, 1930

The meeting convened at 2:30 o'clock, Vice-President McKibben presiding as Chairman.

Chairman McKibben: Will the meeting please come to order?

We are apt to think that everything we do is new, but I am wondering this afternoon whether welding is as new as we think. A few moments ago I visited the Field Museum, diagonally across the parkway here, to see the Roman bathtub that rests in the entrance to the museum. It is made of five pieces of bronze, brazed (welded) together, with handles attached by bronze rivets.

The Curator of the Field Museum informs me that the tub was taken from the Roman palace in the first century after Christ. So there is a Roman tub with rivets and welds living in peace and harmony these 2000 years. (Laughter.)

Discussion Paper by Mr. J. C. Hodge of the Babcock & Wilcox Company, "Application of Fusion Welding to Pressure Vessels."†

Chairman McKibben: Gentlemen, you have heard a very excellent presentation of this subject. The paper is printed in the white reprint. Who would like to be the first one to discuss it? I am sure there are some members of this audience who have more or less decided views on pressure vessels. We should like to have some constructive criticism.

Dr. Ancel St. John (St. John X-Ray Service Corporation): I don't quite know whether I am the daddy or the mother of the X-ray installation down there, but I know that I had a great deal to do with the starting of it, and I also know that I had something to do in the way of labor in bringing it forth to realization.

I want to congratulate the Babcock & Wilcox Company for the vision that they have displayed in going at this new development from the point of view not only of making satisfactory vessels and proving

†Paper published in the October, 1930, issue Journal of the A. W. S.

to themselves that they can make satisfactory vessels, but in proving to all who may be interested that the vessel is capable of performing the service for which it is intended.

It seems to me that in these days of increased temperatures, increased pressures, increased requirements on the materials that go into service, the matter of what might be called non-destructive tests is exceedingly important. You have heard of a development within the last few days going beyond the realm of the X-ray as in the present form, namely, the use of radioactive materials. There are other methods, you have heard of the magnetic test and so on, and it seems to me that it would be very well for all those interested in the development along similar lines to be thinking very seriously not only of the tests of this sort that have been proposed but of any other sort of the wildest kind of notion that might possibly be brought down to earth and tamed.

Mr. H. F. Moore: In discussing Mr. Hodge's most interesting paper I should like to emphasize as strongly as I can the importance of developing a non-destructive test which can be applied to welded joints to detect flaws in them. If we try out a welded structure or vessel with a load one and one-half times the working load, how can we be sure that this overload has not started cracks in the weld or in the base metal?

Mr. Hodge has given us a very clear presentation of the use of the X-ray, and of the Sperry method; the possibility of magnetic tests is to be discussed later, and yesterday we heard of the possibilities of the gamma ray.

I am also much interested in the acoustic method of searching for flaws. You probably have read Mr. Kinzel's account of his tests with the stethoscope. My own experience with that instrument is that by using a stethoscope and a light tapping hammer it seems possible for an inexperienced observer to detect rather large flaws. There seems to me to be a possibility of developing a test in which the sensitivity of the human ear to overtones from the hammer blow may be replaced by some means of optical or electrical recording of wave form.

I believe that the development of welding might be markedly accelerated if three or four non-destructive tests for flaws in welds might be given intensive study in the immediate future.

Mr. Owens: This is one of the most valuable papers that has been presented on pressure vessels. It is valuable in that it gives a fairly comprehensive analysis of the base metal, the weld metal, and the fusion zone.

We have heard in the past that a weld could not be accepted for pressure vessels because of its brittleness. However, the test results given by Mr. Hodge clearly indicate that weld metal can be obtained by at least one concern which is not only not brittle but is tough.

While the Babcock & Wilcox Company have developed a covered electrode which produces welds with characteristics practically equivalent to or probably even better than those of the base metal, never-

theless, other manufacturers are also obtaining similar results with the resistance, thermit, gas and arc processes. A few years ago we would have found it very difficult to locate more than one or two concerns capable of producing the welds shown and described by Mr. Hodge.

Relative to the success of the non-destructive method of testing welds, it appears that the X-ray method as installed by the Babcock & Wilcox Company for the testing of welded boilers, will depend upon whether it can be done cheaply, to what extent it can be used, and on what thicknesses of metal it can be economically applied.

If the Babcock & Wilcox Company can show from experience that welds can be X-rayed at a relatively low cost, then it seems to me that the X-ray as a non-destructive method of testing would not only be universally applicable to pressure vessels but should be required, for there is no test, to my knowledge, which gives such a clear indication of the value of the weld.

It is hoped that Mr. Hodge will throw some light on the speed and the cost of X-raying a vessel. Suppose it costs $100 or even $200 to X-ray a $23,000 vessel, the cost would be nothing compared with the mental satisfaction of a customer in knowing that he had a sound vessel.

D. B. Wesstrom (Research Engineer, M. W. Kellogg Co.): This paper by Mr. Hodge is a very valuable one indeed. The time allowed for discussion of it is too short to do it justice, so that my remarks and criticisms will be necessarily somewhat brief and sketchy. For some time there has been a need for a paper such as Mr. Hodge has contributed here today, and his clear and complete handling of the subject has filled that need very happily. To many of you this may be your first close acquaintance with what represents the highest type of weld that the art can produce. I doubt if there are more than a half dozen concerns in this country today, if that many, who are equipped and competent to perform such welding commercially.

The Research Department of the M. W. Kellogg Co. spent several years in developing a ductile weld which is now being commercially produced in our own shops. It is remarkably similar to the weld described by Mr. Hodge, although the welding procedure, electrodes, and/or fluxes, may be somewhat different. It is, however, interesting to observe that two organizations, working independently of each other in search of the best arc weld that can be made, have secured practically identical results. The idea that the weld metal must be equivalent in physical properties to the base metal is perfectly sound, and when this has been accomplished it is unnecessary to go any further.

There is one important particular in which I cannot agree with Mr. Hodge, and that is in the matter of X-ray examination of every inch of weld. Very small blow-holes, and a certain amount of porosity are admittedly inevitable in a fusion weld, and it is impossible to prevent or repair these minor defects, if they can be called defects. The presence of these small blow-holes or slight porosity does not weaken the weld, as evidenced by the fact that tension test bars taken

transverse to a ductile weld containing such minute defects will still show 100 per cent efficiency as compared with the base metal, even with holes drilled in the weld to reduce the net section.

In regard to large and dangerous defects, such as large blow-holes, slag pockets, etc., our own experience in the Kellogg Co. shows these can be detected immediately by the operator at the time of welding. Cracks in the weld can be prevented by proper welding procedure. If they *should* develop they can be detected by ordinary inspection in conjunction with the hydrostatic test of twice the working pressure. I feel, therefore, there is no need for an elaborate and expensive test procedure such as required by X-ray examinations and electrical flaw detectors. Moreover, there are many practical obstacles in the way of adopting such tests. As an instance, there is scarcely a state or insurance company boiler inspector in the country today who is prepared to conduct or interpret such tests. Such tests as X-ray or radiograph examination are excellent implements for research work in a laboratory for developing or proving a welding process, but they have no place in shop routine.

For instance, the X-ray or similar examination of circumferential seams where the required efficiency is only 50 per cent of a longitudinal seam is most unnecessary for the reason that if it is expected to find flaws of a magnitude of 50 per cent or even of only 20 per cent there is something radically wrong in some stage of the welding process. The statement that the securing of welded samples representative of the joints in the vessel itself presents a serious problem indicates that the results secured with separate test plates cannot always be duplicated in the vessels or in other test plates. If this is the case then again something must be wrong with the welding procedure, the apparatus, or the operator. This is also true when a defect cannot be detected during the welding operation itself.

It must be remembered that the importance of small defects is greatly magnified in the repeated pressure tests as described in a recent paper by Professor Moore, since the range of stress and the number of pressure cycles are much lower in actual service. It must also be remembered that one purpose of the safety factor in any pressure vessel code is to take care of such minor defects.

Mr. A. V. DeForest (American Chain Company): Gentlemen of the Welding Society: It might be of interest to you, in view of the conflicting thoughts on non-destructive tests: Some very flattering remarks that we have heard, and some not quite so much so, to know that the Mining and Metallurgical Engineers are now organizing a committee to take charge of the development and propagation and general dissemination of non-destructive tests of all kinds. We hope thereby to bring into one camp everybody with non-destructive tests and let them show their stuff subject to critical examination, and if it can be shown that it is of interest, then publish results that will mean something to everyone.

These methods apply both to non-destructive tests of materials and non-destructive tests of welds. We hope to encourage the notion that

the non-destructive test, whether it be sonic, electrical, magnetic, X-ray, gamma ray, or any other ray, will have a home in which it can meet other members of the family, and then if it survives be disseminated with some degree of authority. (Applause.)

T. McLean Jasper (A. O. Smith Corp.): I will not attempt to fully discuss the paper because I have not had a chance to read it. However, since I have been called upon by the Chairman, whatever I might say may not be to the point.

With reference to the non-destructive tests of vessels a hint was given by the author that the tests he describes might involve considerable time and expense.

Based on a considerable experience, it is my firm belief that non-destructive tests such as are described should be used only on the development of a welding process and not as a service test. Unless a welding process will consistently produce results which will render such tests out of place such welding should not be allowed in pressure vessels at all.

There is no question today but that sound welding can be done consistently. The practical application of non-destructive tests by the State Boiler Inspectors and their subordinates is one which the writer has discussed with several of them at various times. To the inspecting, and may I suggest also to the using, groups a practical physical test is far more convincing and is to the point. It not only tests the welds but the steel and the designs as well.

It is my firm belief that if the application of a process of welding cannot avoid the things which X-ray for instance discloses, then firms doing such welding should not be allowed to weld high pressure vessels. You will ask how can we tell if a weld is physically good in the application of welding. The answer is to test the finished product physically in a severe manner, and also to test welded samples made at the same time to destruction. The X-ray will tell you nothing about strength, ductility and energy-absorbing properties of a weld.

May I say frankly that the advocates of the X-ray method of testing welds in boilers have either had no welding experience or that they are just in the state of babyhood in development.

I also include the magnetic and electric method of analysis in the above category.

With reference to fatigue testing of boilers the writer is convinced that it is not a fatigue problem. Had it been such a problem the use of boilers would have disclosed it as such long ago. If at this time it is demonstrated to be a fatigue problem, then all boilers, in whatever manner made, should be so tested.

Mr. Morris (Power Plant Engineering): Mr. Hodge, at the higher temperatures, do the physical properties of the weld metal and the plate metal bear the same relation as at lower temperatures? Rather, my question would be: What are the properties of the weld metal as compared with the plate at, say, around 700 deg. Fahr., which would

be the maximum for drums subjected to saturated steam; at temperatures of around 800 deg. Fahr., with superheated steam conditions; or 1000 deg. Fahr., which we may have within the next year or two?

I was wondering, too, on the bare electrode, if the comparative results which you gave were results of welds made in your shops, or if they were samples made by people who claim to be authorities in that field. I was wondering if you have had the same results for the covered electrode rods used by other companies.

I don't entirely agree with Doctor Jasper and the Kellogg gentleman regarding the use of X-rays. It seems to me that the psychological results on the public are rather important. I have talked on this matter with Doctor Jasper before, and I feel, or rather he has convinced me that so far as the welder is concerned the real value of the X-ray is in the development of the welding process. But the man who is going to buy and install these pressure vessels is not a welder, perhaps he is not sure that the welder can tell when defects show up. The X-ray, which I believe Mr. Hodge will tell us is not an expensive process, gives the user something tangible to look at, and it removes a good many doubts from his mind; that is, it gives him something that he can actually see rather than trusting blindly to the ability of the welder whom he does not know.

J. C. Lincoln: I am sorry I didn't have an opportunity to read Mr. Hodge's very interesting paper, but I should like to make one or two inquiries. On Plate X, page 109, there are two cases with what looks like the welded seam. What I should like to inquire is: What are those black marks that appear in the picture? The same question also applies to Plate XIII on page 112. I assume that on page 114, in Plate XV, the square mark at the top of the figure is due to an iron clip which held the photographic plate in place. If that is not correct, what is the cause of that square mark in the upper part of the picture?

With reference to the X-rays, I will tell you a little story. When I was in school in 1887 in Columbus, the building of concrete buildings was somewhat in the stage that the welding art is today. Concrete buildings weren't being put up as well as they are now. It happened at that time that a slab of concrete fell and killed four workmen one afternoon on the Board of Trade Building in Columbus. At that time, naturally, there was a good deal of excitement. A proposition was made and brought before the City Council of Columbus to prohibit the method of building such structures of concrete because of the danger of serious accident. Fortunately, no action of that sort was taken, and we now know from experience of many years that safe concrete buildings are constructed, and we can be assured that when a concrete building is constructed we can depend upon it.

We have to depend, in a concrete building, on the way the job is done. Thirty-five years ago it would have helped a good deal in the psychology of the thing if we had a method of looking into the concrete with something like the X-ray and seeing and being certain that the concrete was uniform throughout, that the mixture was as it

should be. Experience since that time has shown that methods of that sort, at the present time, anyway, are superfluous. I am rather inclined to think that the same thing five years from now will be the feeling with reference to the examination of welds. (Applause.)

Chairman McKibben: Mr. C. W. Obert, of the Union Carbide and Carbon Company, whose connection with the American Society of Mechanical Engineers and with our own Society is well known, has sent in a brief written discussion. I have asked Professor Norton of M. I. T. to read Mr. Obert's discussion.

Professor Norton read the discussion of Mr. Obert.

C. W. Obert (Union Carbide & Carbon Research Laboratories): Mr. Hodge's analysis of the present situation in the "Application of Fusion Welding to Pressure Vessels" is to be commended, in that he points out the shortcomings of former practices which have militated against general acceptances of welded construction, and, moreover, outlines the factors that really control the suitability of welded vessels for severe service conditions. The welding industry has long faced this situation, and it is decidedly refreshing to observe the real points of issue brought out in the open and discussed without reserve.

During the past four or five years a great deal of attention has been paid, both in this country and abroad, to the question of regulations which will ensure safe construction, and it may here be noted that to a large extent the tendency has been toward specification of the procedure that should be followed during construction in order to ensure safe and sound welding. The increase in diversity of processes and procedures as fusion welding has been developed, however, has served to greatly complicate this method of control, and of late attention has been given in this country at least, to possible methods of checking the completed structure with acceptance tests, entirely without regard to the process or procedure followed in construction.

The facts and data presented by Mr. Hodge would appear to indicate that there are a sufficient number of critical methods of analysis of welded construction to enable the latter method of checking welded pressure vessels and boiler drums by acceptance tests to be satisfactorily worked out. Assuming that equality of the deposited weld metal with the base metal is the desideratum, it only remains, then, to determine whether Mr. Hodge's array of tests will accomplish this. He submits the following:

1. Macroscopic and microscopic examinations;
2. Tensile tests;
3. Bend tests;
4. Impact tests;
5. Fatigue tests;
6. Density of weld metal;
7. Chemical analysis of weld metal;
8. Non-destructive tests:
    a. Magnetic;
    b. X-ray.

The writer agrees with Mr. Hodge's premise as to the quality of the deposited weld metal, but is of the opinion that item 1 (macroscopic and microscopic examinations) is undesirable because such tests are not critical and not easily interpreted by an average boiler inspector; that item 5 (fatigue tests) is undesirable because a small number of alternations of pressure will reveal nothing concerning a well-made vessel, while a large number is liable to damage such a structure; and that item 7 (chemical analysis) is undesirable because it is not a definite or direct indicator of quality of the weld metal. Of the remainder, the writer believes that items 2 (tensile tests) and 3 (bend tests) are important requirements; that item 4 (impact tests) is of considerable value, in that impact determinations have been shown to be a check upon the bend test for ductility; that item 6 (density) is of advantage because it indicates the degree to which porosity in the weld metal has been eliminated; and that item 8 is important if the X-ray method is followed, as it will provide a permanent record of quality of the welded joints in a drum, that can be filed with an inspection authority for future reference. (Possibly the same may be true of the magnetic method of analysis, but we are not as yet sufficiently familiar with it to know.)

The writer agrees thoroughly with the author's views as expressed under the heading "Test Procedure," as the three items therein outlined will certainly show with a great deal of certainty the quality of joint and reliability of structure that may be expected. Under item 1 in that tabulation, I would recommend testing of the welded sample plates for (a) the determination of tensile properties; (b) the ductility under bending; (c) the impact values; and (d) the density of the weld metal—these properties to comply with as rigid a specification as will be reasonable for guaranteeing high quality of weld metal. Under item 2, I recommend the X-ray analysis as the most critical and exact method of non-destructive test that has as yet been developed for welded joints; the cost of X-ray equipment is not beyond the reach of any well-equipped fabricating plant, and its operation is safe and certain. Under item 3, I recommend the same hydrostatic test that has always been required for welded pressure vessels in Par. U-78 of the Unfired Pressure Vessel Code, namely, to one and one-half times the allowable working pressure, with hammer test of the welded joints and subsequent increase of the hydrostatic test to three times the allowable working pressure.

It may be of interest to here point out that for over a year the A. S. M. E. Boiler Code Committee, in cooperation with a conferring committee of this Society, has been investigating the possibilities of acceptance-test specifications for welded pressure vessels. After a preliminary study of various data and recommendations, the proposed specifications for such tests were published in the March issue of the American Welding Society Journal, and simultaneously in the March issue of Mechanical Engineering, for public discussion. These specifications were discussed at a public symposium at the annual meeting of the Society in New York, in April, and also at a similar symposium during the annual convention of the National Board of Boiler

and Pressure Vessel Inspectors, held in Chattanooga, in June. The Boiler Code Committee, in cooperation with the A. W. S. Conference Committee, has since been reviewing and digesting the criticisms and recommendations embodied in the discussions on those occasions. It is expected that these studies will result in practical and workable specifications that may be issued in the near future for the use of the public.

Professor Norton: May I say it is very gratifying indeed for those of us who have been interested so long in the development of the x-ray method to find here a really practical application to practical problems. I think it would be of interest to most of us to have Mr. Hodge tell us what some of the defects are which he finds in the x-ray method. We, of course, are all aware there is not a perfect method of test, not 100 per cent perfect, and I think it would be very interesting indeed to realize and understand what these limitations are, although they may not be sufficient to condemn this as a method of test. Personally, of course, I am enthusiastic about the method because it has been my interest for some time, but I think the best way of encouraging the method is to know all about it, to know its defects as well as advantages.

Chairman McKibben: I was intending to pursue this subject to the utmost limit, but the time is passing and we will have to ask the writer of the paper to give his brief answer to these criticisms and questions and then we will pass to the next paper.

Mr. Hodge: Mr. Chairman, I first want to apologize to Mr. Llewellyn for not appreciating immediately the humor of his remark. Having been born in the British Isles, I have the characteristic attitude of the Britisher toward humor. (Laughter.) I was further handicapped by having been born north of the Tweed, and being a Scotchman I became very much excited when I heard of a $2 value selling for $1.99. (Laughter.)

The entire criticism of the paper has been centered around the nondestructive test or the X-ray examination of welded joints. I anticipated Mr. Owens' question regarding the cost of X-ray examination as applied to the production examination of welded joints in pressure vessels. The figures, which I shall give, are estimates and estimates only, as we have not done a sufficient amount of X-ray work to determine exactly, that is, to the nearest five cents per linear foot of welded seam, just what the cost will be. For ½-in. plate the cost will run approximately 30 cents per foot; for 2-in. plate the cost will be approximately 36 cents per foot; for 3¼-in. plate the estimate is as high as $2.63 per foot. Bear in mind that the cost of X-ray examination of a pressure vessel is small in proportion to the entire cost of large welded pressure vessels. If we have 80 ft. of welding to explore and the cost is $2.50 per foot, that is only $200 for X-ray examination or for positive assurance that there are no large defects of any kind present at any point in the welded joints of a pressure vessel with a wall thickness of over 3 in.

Replying to Mr. Wesstrom of the M. W. Kellogg Company, you will

note that I have stated in the paper that there would be a considerable divergence of opinion regarding the non-destructive test and it is only a matter of opinion. However, if I were a purchaser and user of welded pressure vessels, I would want an X-ray examination of the welded seams if it were at all possible to obtain such, and it is possible, and economically possible at that.

As far as porosity is concerned, I have said nothing as to whether a joint, proven to be porous by X-ray examination, should be acceptable or not acceptable. That is the consideration of a governing body of engineers, such as the Boiler Code Committee of the American Society of Mechanical Engineers. Some porosities are dangerous; other porosities are not so dangerous; any degree or type of porosity in weld metal is objectionable if our hope is that weld metal will be generally considered as at least equal to plate material in quality. There should be a limit as to what amount of porosity should be acceptable.

So far as the difficulty of training inspectors in X-ray technique is concerned, the inspectors will not be called on to conduct the actual exposure of the film. They will be presented with prints of the X-ray films of the joints identified in a suitable manner, and it will take only five minutes to explain to an inspector what defects are acceptable and what are not acceptable. A set of X-ray prints, showing several types of welded seams, could be available for reference to by the inspector.

Mr. Morris has asked what the physical properties of the welded joints are at high temperatures. We are preparing another paper on the physical properties of those welded joints at high temperatures, that is, in the range of 600 to 1000 deg. Fahr. The data we have at hand indicate that the welded joint is just as good as the boiler plate at the high temperature.

I place a great deal of faith in the notched bar impact test, and the impact test results which we have obtained on weld metal at high temperatures follow very closely the impact value-temperature curve or diagram of boiler plate and other low carbon steels throughout the entire temperature range. That is, the impact value increases up to approximately 300 deg., decreases from that temperature to a minimum at 900 deg., and then rapidly rises as we enter the plastic range of the metal.

The bare electrode welded joints, from which data on the physical properties were obtained, were made in our own shops by thoroughly competent operators. We believe that we can make just as good bare electrode welds as that made by advocates of bare electrode welding. Please understand, we are not criticizing bare electrode weld metal. There is a very important place for that in the welding of engineering structures.

Regarding a comparison between covered electrode weld metal and bare electrode weld metal, you can get just as bad weld metal with the use of a covered electrode as with a bare electrode. However, it is very much harder to produce a poor weld deposited from a good covered electrode than from a bare electrode.

Mr. Lincoln's remarks, I presume, referred to the black lines crossing the photograph of the surface of the fracture in one of the fatigue tests. Those black lines were due to the sectioning of the steel containing the defect, the black lines or zones corresponding to the metal removed by the cut. For example, if this represents a welded joint and we have a crack or fracture in this position, we cut the fractured zone from the shell and then proceed to section this zone. Having obtained the sections, we examine the sectioned surfaces and then split each section along the fracture. By placing each section in its original position and then spreading the sections open just like a book, we obtain the two surfaces of the fracture as shown in the photograph. Does that answer the question?

Mr. Lincoln. Yes. I was trying to find out what made them. That answers the question.

Mr. Hodge: In commenting on the black marks on the photographs, were you referring to the radiographs?

Mr. Lincoln: At the top of page 114.

Mr. Hodge: Where there is a black mark? That represents a lead marker which was placed on the boiler plate to the side of the welded joint as a reference point. That lead marker absorbs the X-rays, so that no rays strike the film immediately back of it. When the film is developed, the image of the lead marker on the film is colorless, so when we make a photographic print this area is represented as a black zone. Is that what you meant?

Mr. Lincoln: I thought at first it was probably some clip.

Mr. Hodge: Could I see that photograph? That is the image of the lead marker. The purpose of the lead marker is this: We place those lead markers at distances of 12 in. along the welded joint. The lead markers are prick punched, and the resultant hole in the lead marker is shown on the X-ray prints. If a defect is present on the X-ray film or print, by referring back to the lead markers the defect can be accurately located in the welded joint. Is that sufficiently clear?

I don't believe there is anything else I can add. With regard to X-ray examination, it is only a matter of difference of opinion, and I will leave it to each one of you as to just what you would accept if you were buying a welded pressure vessel.

Discussion paper, "Magnetic Testing of Butt Welds,"† by T. R. Watts, Westinghouse Electric & Manufacturing Company.

Mr. Harcourt C. Drake (Sperry Products Company): Mr. Watts has covered in his very comprehensive paper this type of weld testing and has taken a commendable attitude in pointing out the value of it and its discrepancies where it has any.

I would be interested in having him tell us whether or not he has made any tests where the specimen has a fracture in which the faces of the crack are in intimate contact, say under pressure. I should also

†Paper published in the September, 1930, issue Journal of the A. W. S.

like to have him tell us whether he has tested material of, say, 2 or 3 in. in thickness, and if so just what results were obtained.

Mr. Watts: I haven't had any invisible cracks to test, except in forgings, which were not welded. (The iron powder detected the forging cracks, but after etching the surface the cracks could be seen to extend farther than the iron powder indicated.)

We did test a cracked welded frame ring which had got by the regular visual inspection and on to a boring mill, where the machinist discovered it. The crack was almost invisible, but in testing by magnetographs it showed a heavy line of iron powder about ¼ in. wide, which was very conspicuous, of course. (We didn't have the weld test meter then, but laboratory tests show that it also detects cracks very satisfactorily.)

As to the thickness of material tested: so far I have not tried anything thicker than 2 in. We have gotten results on pieces 2 in. by 25 in. in sectional area. I see no reason why the weld test meter would not work for greater thickness.

Chairman McKibben: Is there any other discussion on the paper? Mr. DeForest, have you anything to add?

Mr. A. V. DeForest: I regret I have nothing to add to this very painstaking investigation of the dust method. It undoubtedly offers very distinct possibilities for thin stock. I have used it on some applications up to about ⅛ in. thick, and there it is altogether very splendid. Beyond that I would very much imagine that there were difficulties, especially in the single V weld, for the detection of unfused metal at the bottom of the weld. It is quite easy to confuse evidence of the thickness of the deposited metal and the penetration at the base of the V.

Chairman McKibben: I should like to take one minute of your time to repeat in brief what I said yesterday about an inferiority complex. When I was a student in college I had a professor who dwelt so much on our making mistakes that every time we tried to do any work we were so afraid of making mistakes that we did nothing. Let us not get into that attitude regarding the testing of welds.

The methods that have been described here for two or three days are wonderfully interesting, wonderfully valuable, and no doubt will prove to be an essential part in the development of welding. Nevertheless, if one listens too closely to these papers he becomes imbued with the fear that welds have so many defects as to be of questionable use. This is not the case. Welding has made remarkable progress. It is an essential part of modern industry. It has made possible many operations which before were not possible. All I have to say regarding these many tests is: Good luck to the men who are making them and may they progress to the point where they will be most valuable and most certain in detecting defects in our work. We welcome all such efforts and we must not, however, feel that the defects are so great that safe work never results.

The meeting adjourned at 4.50 o'clock.

FRIDAY MORNING SESSION

September 26, 1930

E. Wanamaker, Presiding

Discussion paper, "Double Lengthening Railroad Rails,"† by L. C. Ryan, Oxweld Railroad Service Co.

Chairman Wanamaker: Gentlemen, you have all heard Mr. Ryan's most excellent paper on what I feel is a very important subject. I think the Society can be congratulated on the fact that they have given so much time on the program to this subject. I don't know whether or not those not in the transportation business know how serious in the last few years has become the competition with the railroads. Not least among these is the pipeways which the public doesn't often hear about. It would seem as if possibly our greatest competitor today and in the near future will be the pipe lines, especially the pipe lines in connection with highway transport. In addition to these we have the waterway, and last but not ultimately the least in all probability, the airway. So I might safely say, as somewhat a representative of the railroad fraternity, that the railroads are most highly interested in promoting efficiency and economy of operation and maintenance today. But there is one thing that we can't forget; the public won't let us forget it, Congress won't let us forget it, and the Interstate Commerce Commission won't let us forget it. That is the feature of safety. I venture to make this assertion: that on no other line of industry, effort or business is the safety burden saddled as it is upon the railroads. I wish each and every one of you would carry that message home, give it some thought and spread it about.

Danger on a railroad means a lot. It apparently doesn't mean a whole lot in some lines, nobody is making any particular effort to protect our citizens from the results of high life, fast life, questionable gin, automobiles and all that sort of thing. But it is lese majeste and treason to the king when we cause the slightest accident anywhere.

I know that I will have the well wishes of all my railroad friends and coworkers in leaving that message with you. As Mr. Ryan has just said, one of the most expensive factors in the maintenance of railroads is that of track maintenance, and it is becoming a more important factor daily since the railroads are constantly endeavoring to increase train loads for economy's sake and train speeds for the benefit of the patrons and customers.

If we could eliminate the joint entirely it would no doubt be one of the greatest improvements that have been made in railroading as we know it in this country, and I think in view of the importance of this subject we should have a great deal of most interesting and helpful discussion.

I wish to say to you that those railroad men of ability and those in authority with whom I have conversed quite naturally show a fear that is inherent when we start to apply heat to track rails in the open

†Paper published in the September, 1930, issue Journal of the A. W. S.

track on the main line, because those who approve such practices are, to say the least, held morally responsible.

I can go back, gentlemen, to some of my early experiences in railroad welding. I don't know whether my hair became gray because of some of those experiences or not, but I think I can attribute some of them to the fact that many a night I went to bed wondering whether I might not have caused a death. It is not so pleasant to think about. We tried, as pioneers, some things that we don't do today.

At that time we had not the benefit of scientific men and engineers with years behind them in research, experiment and development to guide us. We, as a rule, had to just reach out and try something without any data or information which might make us feel that we would not cause serious accidents. Today it is an entirely different story.

While I have not been as active in welding in the last few years as I would like to have been, I have tried to keep pace with the developments by reading that which has been written, and especially the discussions of what has been written. I should like to say that it seems a much simpler and easier matter today to develop new methods and processes than it was back in 1917, a lucky thirteen years ago.

We are looking today for many things, Mr. Ryan, not only improvement in track maintenance, but we are wondering and expecting some Moses to come forth and show us a real economic method of building cars. We know that we haven't made any big improvement in car construction cost. The railroads realize today as they have never realized before that we must increase, very much increase our efficiency, as well as to render an improved and better service more in keeping with the demands of these modern times. But we have not command of many of the mental resources that are primarily necessary and the physical resources that must follow in after these mental resources if we are to have the improvement that we know we need and desire.

Unfortunately, sometimes we become a little pessimistic and think that the manufacturer who does have the facilities and who does develop new ideas is grinding his own axe much harder than he is our own, and we wonder sometimes if he is fully cognizant of our troubles and difficulties and if he is making all the effort he might to help us with what we might have to live with after we once get it. A railroad can't drop anything and it is almost impossible for a railroad to get rid of anything once it gets it. You might have a line 15 miles long that serves absolutely no economic service or advantage to the community, but they insist that you keep it running just the same.

I went to a meeting at the request of another railroad not long ago to help them in placing their case before the hearing. The people wanted to retain a passenger service regardless of the fact that they hadn't hauled a passenger in some ninety odd days, and that every objector at that hearing had come in his own automobile and didn't even ride in a bus. (Laughter.)

So we want you, while you are developing these things, helping us, to help us live with them as well. Mr. Ryan, if you and those who

take part in this discussion will bear that in mind, it will help us fellows a lot. (Applause.)

Gentlemen, the paper is now open for discussion.

Mr. Ryan, could you explain the method of making these welds somewhat in detail?

Mr. Ryan: Well, as a general procedure?

Chairman Wanamaker: Yes, especially the butt welds.

Mr. L. C. Ryan (The Oxweld Railroad Service Co.): We found, in the development of and getting a most successful butt weld, that we must have a welder who is interested and one who knows how to weld.

The rail is V'd out on the base, web and ball so that there is plenty of room to get the nozzle down into bottom part of the V everywhere in order to make a perfect weld. While the weld is being made, allowance has to be made for the contraction of the various thicknesses of rail section.

Rails are set up workways, V'd out and the complete weld is made without disturbing the rail. First the base is welded, then the web and the ball is the last point finished. The web and base are welded with one of our regular special rods. The ball is welded with a patented rod which is used also for rail end welding. No reinforcement is left on the rail section.

Chairman Wanamaker: The angle bars are applied in the usual manner afterward?

Mr. Ryan: Yes. The angle bars are applied after the weld is made, preferably usable angle bars. The angle bars are applied not to support the weld; they are applied, as we welders know, because sometimes a man if he is careless might not make a perfect weld and the weld might break. We have had broken butt welds. Out of 20,000 or 30,000 butt welds we have made this year, there have been only a few breaks. They will crack up through right where the rails are united. If the angle bars are on, it is still a regular bolted rail joint. Being a regular rail joint, all it is apt to do is break the signal circuit. We haven't had any breaks that we couldn't reweld. We have had success after rewelding, and in every case we found the trouble was just a little careless welding in the first place.

Chairman Wanamaker: You have had no trouble from any undue or bad heat effects set up?

Mr. Ryan: To the best of my knowledge we haven't had any rail that showed any indication of breakage on account of heat effect.

I showed one tunnel picture and out of about 1240 welds made on that job I think there have been three rails showing a fracture in the weld, which was very pleasing to us. It gave us assurance that if butt welding was properly supervised and if it was done by a welder who knew how to weld, and who was interested in making the weld, the safety element would not hinder the development of the project.

We started this operation on railroads and went at it cautiously by welding rail on slow speed track at first. Now there are a number of

railroads interested in extending the operation to open track. No doubt there are men sitting here in this audience who are interested in it, and I heartily concur with you in saying that I should be interested to hear discussion on this subject.

Chairman Wanamaker: Is there any discussion, gentlemen?

Mr. John C. Reed (Bethlehem Steel Corp., Scranton, Pa.): I should like to ask whether you have ever made any drop tests on these joints which you are welding, and if so, how they compare with the tests required by the railroads on the original rail.

Mr. Ryan: I think that drop tests have been made and some very favorable reports have been given.

Chairman Wanamaker: Are there any further questions for Mr. Ryan to answer on the paper?

Mr. Llewellyn: I did not catch whether he explained if the process of making the weld requires that he preheat the rail for any considerable distance back from the joint.

Mr. Ryan: In making the butt weld we make no pretensions of heating it before we start. While V'ing out and during the welding operation the entire rail end gradually becomes heated up for a considerable distance both ways from weld which is sufficient preheating.

I inspected some butt welded joints in Boston on the Boston Street Railways which were thermit welded. It was a very good job. It was on a grade. I should say that it is a quarter of a mile or so of open track except through the different street crossings. It has been done, I think, for a couple of years. I inspected it last summer and found that it has given very good results. It is a good stretch of track for anyone in Boston to look at and see what continuous rail welding will do on open track where it is subject to various extreme changes of temperature. I mention this because I am interested in finding out how expansion and contraction would affect this particular stretch of butt welded rail.

Chairman Wanamaker: Mr. Ryan, recently I witnessed a train telephone test in which the despatcher 250 miles away was in touch with both the head end and the rear end of a freight train by telephone, and it worked very nicely. There was also a code signal system between the rear and head ends of the train. In this test they had a wire or conductor for induction purposes down the center of the track, that is, midway between the rails, they stating that without the wire apparently the click of the wheels on the rail joints made a noise that was difficult to overcome. Since I have heard your paper this morning it occurred to me that possibly if you got the rails smooth they wouldn't need the wire as they wouldn't get that click.

Is there any further discussion, gentlemen, on this paper?

Mr. C. S. Purves (Quasi-Arc, Incorporated): Mr. Wanamaker has rightly suggested that the question of heating the rail, particularly on open track, is of vital importance. Mr. Ryan has said that the rail is V'd, which, of course, it must be. Perhaps he will tell us how it is V'd. If with the oxy-acetylene torch is the carbonized layer removed before welding takes place?

Mr. Ryan: I will answer that by saying yes, sir, the same as we take the oxidation off for any weld we make.

Chairman Wanamaker: Are there further questions? Otherwise, Mr. Ryan, we thank you most kindly for your good paper, and later on as we discuss the other papers, should any questions come up in connection with yours we shall be glad to bring them in at that time.

Discussion paper, "Possibilities of Further Development in Railroad Welding"† by Mr. G. W. Lieber, Superintendent of Reclamation, Missouri, Kansas & Texas Railroad Company.

Chairman Wanamaker: Gentleman, you have all heard Mr. Lieber's most excellent paper and I think he has given us plenty of opportunity for discussion. We should be glad to hear from you with any questions you may have to ask Mr. Lieber. I am always good at asking questions, Mr. Lieber; I should like to know what particular subject, outside of rail welding, which we have discussed and will discuss again, offers the nearest development or the quickest development, in reclamation work for example.

Mr. Lieber: Car castings of steel offer the best possibility at the present time. While at the present time welding is somewhat limited, due to certain objections of the committee that I referred to in the paper I can see no reason that it cannot be advanced to other similar articles which are now absolutely prohibited or prevented from being welded in any manner. On these particular castings on which they do not permit welding, they do permit, however, the building up by either process. Our contention as a committee is that there is as much stress set up through building up as there would be through welding. If the article is damaged to any extent by welding it would be equally damaged by the building up. Car castings and similar castings on locomotives and tenders offer the best possibilities in railroad welding at the present time, together with manganese, which is a very vital subject to the committee this year. It is the welding of manganese and the extension of welding car castings, which we hope to obtain, especially couplers.

Chairman Wanamaker: I think Mr. Lieber made a statement that it seems to me with welding men could stand for a little discussion. Are the stresses and strains the same in building up as they are in what would we say—joining together?

Mr. Lieber: There is a possibility of it not being so great in building up as it would be in actual welding, but there is a stress and strain set up by the application of a torch, regardless of whether it is welding or building up.

Chairman Wanamaker: Then might this be a question that is involved? Not the difference possibly in the stresses and strains, but in the use to which the article is put?

Mr. Lieber: They could hardly attribute that to use of the coupler. A coupler stands both strain and compression, but the strain that would be set up, due to welding or rather to building up, would not be

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any more than it would be subjected to. It would not be subjected to any harder use if welded than when built up.

Chairman Wanamaker: I don't want to ask all the questions, but I want to learn something if I can. Would this be a factor: In a building up job, due to the human factor or the failure of the operator, the weld lacked a great deal of being a good weld, even so, providing the part that has been built up because it was worn has not been worn below the condemning limit, means that there would be no failure such as might be even if the parts that had been welded together broke away from each other in case the weld failed?

Mr. Lieber: From that standpoint there would be more possibilities of failure due to the welding than due to the weld. That is hardly the contention of the American Railway Association, so far as our division is concerned in connection with the Mechanical Division. Their contention on couplers is that all railroads are not equipped to properly carry out a process that might be recommended and accepted, and the possible danger in failure in a coupler is so great that they hesitate and have hesitated for some time in accepting and permitting welding to any degree on couplers. A truck side bears just as important a relation to the operation of a car and a train as a coupler, in my opinion, more so. A coupler is subject to strain pull and compression. A truck side bears its proportion of the weight of the entire car. A failure on a truck side could cause a wreck immediately, while a failure on a coupler, under the present air equipment, would only result in the train being brought to a standstill. There would be a possibility of the car leaving the track, but the damage would be very much less than it would be in a failure of a truck side. While Division V permits welding of truck sides, they have objected to the welding of couplers. We have fought with them for five or six years, and I believe this year we will succeed in convincing them that it can be just as easily done and as well done and be as safe as it would be on a bolster or truck side. If we accomplish that we have not only done something for the welding fraternity but we have done something for the railroads that will be the means of effecting many millions of dollars of savings.

In your Chicago district here alone I know of one railroad where they wouldn't even permit the building up of couplers, and I was informed by one of their officials that they disposed of, from the entire system, as much as 175 tons of couplers per month. The majority of them, in his opinion fully 80 per cent of them, could be reconditioned at a small cost and put back into service and give equally as good service as new couplers.

You can just draw your own conclusions from that as to the amount that it means to the American railroads, when one railroad alone in the Chicago district is scrapping from 175 to 200 tons of couplers per month, 80 per cent of which could be saved.

Chairman Wanamaker: Has anyone any suggestions to offer? This is a most important subject to the railroads. I have served several years in the Mechanical Division on this Welding Committee work and we are constantly seeking enlightenment. What importance do you attach to annealing in these various methods?

Mr. Lieber: That is the secret of our protest in bringing and getting consideration from Division V. Prior to that time annealing was thought unnecessary. In fact, welding as a general rule in connection with railroad work was thought of as just another economical process that anybody could carry on to a full degree of safety and satisfaction without any knowledge of the elements with which he was working, the structure of the metal which he was handling, or the process by which he was applying it.

The developments in the past five years have brought about the absolute necessity of annealing, regardless of whether the casting has ever been welded or built up, and especially in cast steel, which opinions vary on. Some opinions hold that the casting will become fatigued under the operation and strain it is subject to in a period of from eight to ten years. We take the stand or the committee is making the recommendation and taking the stand that all car castings be re-annealed at their first shopping, which will be over a period of about ten and not over twelve years, some of them six years. It is highly important and annealing is the reason for welding being entertained by the American Railway Association, Division V. It is through annealing that we have gained the point and have obtained consideration so far.

Chairman Wanamaker: May I ask if you have given any consideration to the kinds of metals used in making the various castings to lend themselves to a greater ease of welding, or have you made any study as to the mechanical design of the casting to lend itself to reclamation or maintenance by the welding process?

Mr. Lieber: Frankly, I have to admit that is a question we haven't handled, as a committee. We haven't given it consideration from the standpoint of design. Of course, very few of us are engineers or designing engineers anyway, and perhaps not engineers at all. We are just trying to help ourselves. We have never given any consideration to either one of the subjects you just asked about, while they are important, nevertheless.

Chairman Wanamaker: It seems to me that those interested in reclamation oftentimes have a means of keeping record as to when and where breaks occur most frequently.

Mr. Lieber: That is being done.

Then, of course, comes the composition of the material that we are using, the material that is handled. So far as design is concerned, we have never taken it up to see if the design could be bettered to prevent a reoccurrence in the same place on a certain structure. However, the point we take on that is this: We reinforce that section, particularly on truck sides, at the present time, that fails in the right-hand corner over the journal box. We have noticed that on particular design of truck side. The mechanical engineers have changed the design of the truck side. Whether it will benefit us any more or not, I don't know, but we are reinforcing the old steel and getting very satisfactory results, annealing it afterward.

Mr. Fred E. Rogers (Air Reduction Company): What is the situation with regard to building up car couplers in general? I got the

slant from what you said in regard to couplers that building up is permitted on yokes.

Mr. Lieber: Yokes are not permitted.

Mr. Rogers: Building up coupler faces?

Mr. Lieber: On faces and shanks building up is permitted. The application of a block to the shank of the coupler to increase the size from 6½ to 8½ or 9⅛ is permitted. But the actual welding of a fracture in a coupler is not permitted, nor is there any welding permitted on a coupler block.

Mr. Rogers: I understood that the yokes on couplers are welded in some instances and permitted.

Mr. Lieber: I agree with you that they are being welded, but it is not permitted by the American Railway Association. I found one just a short time ago through our laboratory.

Mr. Rogers: What is the objection, may I ask, to building up a coupler block?

Mr. Lieber: That is a question that we are trying to get Division V of the American Railway Association to answer. We can't see any reason why there should be any objection to it, but, of course, they are the law and gospel. I think this year we will overcome that and by next June we hope to be able to weld and build up coupler yokes and also weld couplers.

Chairman Wanamaker: Are there any other questions that we care to ask Mr. Lieber? I thought that maybe I could carry something back to Division V.

Gentlemen, if there are no further questions to ask Mr. Lieber, I will take this occasion to thank him for his paper. It was very good, indeed. (Applause.)

Discussion paper, "Elimination of Joint in Open Track,† by Mr. J. H. Deppeler, Chief Engineer, Metal & Thermit Corporation.

Mr. J. H. Deppeler: In the annual meeting in 1929 I presented a paper on this same subject, but that paper dealt more with the developments abroad rather than the developments in this country. I thought at this time you might be interested to know what has been done since and how we have progressed in this country in the development of this particular joint. I think, in order to make the thing understandable, we ought to go back and review a little of the old.

Chairman Wanamaker: Gentlemen, this is a most pertinent subject that Mr. Deppeler has been speaking upon and we should have much very enlightening discussion.

Mr. Ryan (Oxweld Railroad Service Company): Does the author know of an installation of welded open track made by the Boston Elevated Railroad in which Thermit had been used, and which had been entirely satisfactory over a period of two or three years so far?

Mr. Deppeler: I am very sorry to say that I don't know of that particular installation. I have followed, of course, as some of the outside men have, all of the installations made by the street railway compa-

†Paper published in the October, 1930, issue Journal of the A. W. S.

nies. Some of these have gone from the paved track, which we thought at that time was the only thing to weld, to open track. There have been a number of them. I ran into one of them down in Easton, Pa., where they went right ahead and welded without any idea of expansion difficulty, and they haven't had any. So we think those are excellent precedents.

Did you say, Mr. Ryan, that your company had installed more than 20,000 joints on railroad open track in this last year?

Mr. Ryan: Yes, that is approximately so.

Mr. Deppeler: Certainly, we of the thermit industry are tickled to death to see that we have somebody to help us fight our battle with the railroads. We are going to help you and you help us.

Mr. A. M. Candy: I should like to ask Mr. Deppeler if he has some average or typical cost figures on the thermit weld in some specific size rail, say 130 lb., or any other size he may have in mind, including the total charge to be made against such cost of welding.

Mr. Deppeler: Yes, the cost of welding this rail section by this pressure weld method is a little less for material than it would be to make our regular insert weld. That is evident, of course, because we are utilizing not only the heat of the thermit weld, which comes up only to this point, but are also utilizing the heat from the slag which is used in the butt welding of the upper portion. So from that standpoint it costs less, but the application of the clamps to the rail sections in the laying of the track, necessitating the forcing together of the rails as each joint is made, introduces an increased labor cost, which makes this joint, for instance, on the 130-lb. Pennsylvania section, cost about $10 a joint or so instead of $8 a joint. The cost is a little higher, but the results are so perfect that the increased cost is well paid for.

That brings up another thing I had forgotten. To show to what extent some of the railroads are going to overcome the difficulties they are having due to battered joints with the enormously heavy wheel loads, they are going to alloy steel rails, and they are going to heat treated rails. Though they are both excellent developments, I don't think either of them will answer the question as thoroughly as welding because neither will eliminate the joint. All they will do is to make, for instance, rail sections weighing 200 lb. per yard to withstand the 80,000-lb. wheel loads. I think the elimination of joints in the present-day rail section will be very much more effective than the increased rail weight.

Mr. H. M. Hobart (General Electric Company): In continuous rail can that be associated with lighter rail for given serviceability?

Mr. Deppeler: I should imagine so, Mr. Hobart. It seems to me that to make the rail continuous will eliminate some of the difficulties which really are introduced on account of the presence of a joint, and possibly a lighter rail will answer the same service. There is, however, this much about it: The use of the present rail sections with the enormously heavy equipment is only made possible, I believe, because of the elasticity of the roadbed. I am talking here about a lot of

things which are my personal opinion. I realize that a lot of railroad men will probably jack me up in a minute. I am not trying to teach them something which they know more about than I do. We have had, for instance, an installation in the main line track in Syracuse, which is, as you know, in paved streets. One day's operation of those enormously heavy locomotive loads over that rail causes a cold flowing of the metal in the head of the rail so that the center of the top of the rail on which the wheel load comes moves forward appreciably relative to the side portions. We can see this very readily because the seam across the head of the rail at the joint, which before traffic was put on, extended straight across the head normal to the axis, in one day after operation began, the center of this seam had advanced almost ½ in. ahead of the rest of the seam. There is a cold flow of metal in the rail head in the direction of traffic, which has worked the whole center of that rail section ahead. That, we feel, is due principally to the inelasticity of the supporting surface. That installation is on concrete foundation. I do think that the elastic roadbed is an excellent safeguard and is going to make possible the things we hope to do which inelastic roadbeds would not allow.

Chairman Wanamaker: May I ask, Mr. Deppeler, what, if any, breakage you have had in the welded joints?

Mr. Deppeler: In view of Mr. Ryan's statement, I don't like to say that we haven't had any, but we haven't. The difference is this, however: Mr. Ryan has talked about an installation of, I think, 20,000 or 30,000 joints or something like that. What I am talking about is a number of very much shorter and smaller installations. We are not talking about 30,000 joints. In Germany their records, they claim, show no breaks on any of their thermit welded track, although they have installed 60,000 or more joints. But that is all hearsay. In this country in all of the work we have installed we have had no breaks as yet.

Chairman Wanamaker: You say the Lehigh Valley had five miles of track?

Mr. Deppeler: Yes.

Chairman Wanamaker: How long were the continuous welded sections?

Mr. Deppeler: I referred there to an installation in which they had come to the same conclusion that we had, and that is the ordinary rail joint did not function as an expansion joint. It did for a while but quickly rusted and became inoperative. What they have done there is this: Instead of using 33-ft. rails they have doubled the length to 66 ft. They purchased the 66-ft. rails. Then they laid them with their heads tight together with reamed and fitted bolts so that there was no chance for the miniature expansion at those individual joints. They have laid five miles that way.

On the conclusion that there will be no trouble from expansion, I will say that it would make no difference whether those five miles were welded or not, that there is no chance for expansion now, and the welded joints would probably be at least as good as the mechanical butted

joints they have now. I believe that that installation is a definite proof that five miles of track can be laid without any heat expansion difficulties.

Mr. Wanamaker: What was the temperature at the time the Lehigh Valley rail was laid?

Mr. Deppeler: The temperature at the time of laying was given in the article, I presume by Mr. Phillips, and this temperature was 35 to 40 deg. Fahr. After installation they experienced a hot summer in which they had temperatures running over 100 deg., which means rail temperatures of about 135 to 140 deg.

Chairman Wanamaker: Any further discussion or questions?

Mr. Ryan: With Mr. Deppeler's permission I should like to add a little to the Lehigh Valley installation. I understand this steel was laid in the month of March when the weather was quite cold. As all track men know, when any rail is laid it moves more or less after it is laid. For some little time as fast as any expansion developed they closed it up. In other words, as I understand it, and I think Mr. Deppeler also knows, they closed up all the expansion that developed after they laid it. So it was really just the same as continuous welded rail and it went through the summer and winter and was still in good shape this year when the report was made.

Mr. W. O. Freyberg (Ann Arbor, Mich.): According to previous reports it was evident that the expansion of the rail was limited only to the ends, in the case where many rails are welded together. So I understand that, if you consider many rails welded together in a line of track, only the central part of the stretch is not subject to any expansion or contraction from the temperature. If that be so, in this middle part, theoretically, must be set up considerable stresses, which must weaken to some extent the rail. I should like to get some explanation on this question.

Voice from the Floor: Can you give us any idea of the stresses introduced into the rail itself by the tendency for the rail to expand due to temperature change?

Mr. Deppeler: I think I can give a little information on that. One installation, near Berlin, Germany, on the state railway, was an experimental installation of 1000 ft. of track on freight lines. Alongside of this they had 1000 ft. of welded rail lying on rollers, purposely installed so as to avoid friction as much as possible. Then they had trammarks across between the rail and track so they could examine the relative expansion between all parts, from the center to the ends. Their data showed that the welded stretch moved only at the ends, that the whole center section was stationary during temperature changes, and that the actual motion, the actual growth of that entire length of rail was noticeable only on the last rail length on each end. So a bolted joint was perfectly satisfactory on the end. That bolted joint would probably have about twice as much motion as the present bolted joint, because that rail length on the end was expanding in one direction only instead of in two directions. So far as the introduction of stress is concerned, there is absolutely no doubt but that there are strains introduced into the rail, tension and compression, but our

claim is that they are of no moment. They are not important because the real difficulties that a track is subject to are that of fatigue and grain growth and similar things due to the constant bending of the rail and the constant hammer blows and shocks at the rail joint. Those strains and stresses that are introduced that way are much more important than any compression or tension in the rail way below the elastic limit of the rail. One is important and the other is of no importance, practically.

That, of course, has to be proved by experience. We can't, so far as I know, make a test which will prove whether or not it is important. It doesn't seem to me to be of any real moment.

Mr. Freyberg: According to previous reports about testing welds in fatigue and impact, presented by Professor Thornton and Mr. Jennings of the Westinghouse Company, the endurance limits were very low on welds. So I think the most important test of welded joints of rail would be the fatigue test, as a low-endurance limit would shorten the life of the rails. If rewelding of broken or aged through fatigue welded rail joints might be successfully accomplished, this procedure might possibly solve the problem in the case of a low-endurance limit.

Mr. Deppeler: There is no doubt that fatigue resistance, of course, is the most important test. We came to that same conclusion in our Bureau of Standards tests. A great deal of the data that you saw in Professor Thornton's paper on fatigue tests was for fusion welds. That is like this lower portion. Remember that the fatigue testing of the pressure weld was almost equal to the parent metal results. That is this upper portion. Really, there is very little localizing of the bending force as it comes through here. This section is a little larger than the rail section, but very slightly. Although there is a slight tendency to localize the force here at the outer end, it is so slight that the amount of local bending in and near the welded section is only a mere fraction of that which you will get in the bolted joint.

I don't believe that fatigue is going to bother us a bit. I think we are going to eliminate a great deal of the fatigue failures that now exist in track.

Mr. Freyberg: That might not show up at once.

Have you had any experience, any previous experience in rewelding broken welded rail joints? I think that would have a very great influence on the maintenance cost of track.

Mr. Deppeler: The rewelding of broken joints?

I have had none. I am not bragging. We have had none as yet that were broken. I don't believe they are going to break. You will get broken rails, but broken rails probably are due to surface or other defects which gradually extend under the impact and bending stresses.

Mr. Candy: I should like to ask one more question. In that test that Mr. Deppeler described, laying one section of the rail out in the open and the other welded on the ties, were there any examinations made to determine the approximate stress resulting due to the welded rail being spiked to the ties?

Mr. Deppeler: Yes. I have a 20-page report on that which goes

into it very thoroughly. There is this conclusion: that the compression stresses are less important than the tension stresses, that the rail should be welded at a temperature at which the proper compression stresses and tension stresses will be introduced; that we should not weld, for instance, when the temperature is so low that we will get enormous compression stress, or at a temperature that is so high that we will get no compression at any time of the year but all tension. That would seem as though we were going to be limited a great deal in the welding of railroad track, but that can be gotten around very easily. We can get a condition at the joint which will be the same as the condition which that average temperature will introduce, because we have on here clamps which can open or close the gap and give us a condition at the joint which will correspond to the average temperature, by forcing the track structure one way or the other. I would be very glad, indeed, to have a copy of that paper made. It is very complicated, as most of such German calculations are, and it will probably be interesting reading for some time to come.

The strains are unimportant, though.

Mr. Llewellyn: It seems to me that the data presented may indicate not so much the development of welding as the elimination of welding. The joints that have been described are so efficient that I, as one connected with a company producing steel rails, have been wondering if we can't do away with joints entirely. These are the days of continuous processes. We have continuous furnaces, we have continuous bar mills, and what has been presented suggests a vision of a steel mill with larger furnaces, larger heaters, in which we have no cooling beds; the freight cars on which the rails will be transported are built of steel; they will form our cooling beds. We will roll rail continuously, starting from the mills here in Chicago and extending in one unbroken line, and possibly laid at the time of rolling, from Chicago to San Francisco. (Laughter.) Just one question: What are you going to do when you come to the swing bridges? (Laughter and applause.)

Mr. Deppeler: All we hope to do, Mr. Llewellyn, is to tide over the period until your continuous mills are ready. That will give us quite a little welding.

Mr. John C. Reed (Bethlehem Steel Company): I should like to ask Mr. Deppeler what developments have been made along the line of equipment for finishing the rail after the weld is made. A few years ago I was over in New York where I witnessed a process of butt welding rails, a patented process. I don't remember the inventor, but it consisted of spacing the two rails probably ⅜ to ½ in. apart. There was a mold placed around the gap and the space was filled with a molten borax. The current was then passed through the joint until it was sufficiently heated, pressure was then applied and a pressure weld made. That seemed a very simple matter so far as it went, but from there on the equipment was very elaborate. The equipment for grinding the joint after the weld was made consisted of two cars, and they had an annealing car which annealed the pressure weld by means of oil burners. Altogether, it seemed as if it was a very elaborate equipment to use for welding a joint. I would be interested in knowing

just what is necessary in this process of welding in the way of annealing the joint, and in finishing it so it is perfect when completed.

Question from the Floor: I am familiar with another welding process which results in a pressure weld of the entire rail section and in which stresses were introduced which made it very necessary to post-heat. Do you find post-heating necessary with your weld also?

Mr. Deppeler: I think we all know the process you refer to in which an electric weld is made and borax is used as a resistance medium. That is the joint which was tested at the Bureau of Standards and showed up so wonderfully in all its properties.

In making the resistance joint they do have internal stresses because of the effect of forcing the rails together, in which the rail head is forced upward and the rail base forced downward, introducing on cooling, a tension stress tending to crack horizontally through the web of the rail. The annealing, therefore, is necessary in the butt weld and is usually used. I am not so sure whether that will ever be eradicated or not. We have no such trouble in the making of our butt welds. It is a little different from theirs because this entire bottom section here is fusion welded, so that at the time we are forcing the rails together here, it is only the head-part that offers any resistance to that forcing together. We are really pressure welding a bar, consisting of that head portion only. This part down below is all plastic and fusion welded.

Mr. Reed: May I ask just how you get the heat into the head of the rail there? That isn't quite clear.

Mr. Deppeler: The Thermit reaction, you know, takes place in a mixture or iron oxide and aluminum, the aluminum having a greater affinity for oxygen reduces the iron oxide and forms on reaction steel and molten aluminum oxide or slag. This slag or alumina is, you know, a very refractory material. Now, in the reaction the iron formed being heavier, goes to the bottom of the crucible and the slag floats on top. The reaction is exothermic and takes place very rapidly, any quantity of steel being formed in less than 30 seconds. After reaction the steel is tapped from the bottom of the crucible into a mold of this kind, the steel coming out of the crucible first will surround the base of the rail, giving up its superheat, which is approximately 100 per cent, to the fusion welding of the base of the rail, which has been thoroughly preheated. The slag alumina or aluminum oxide will then surround the head portion, and that slag is two-thirds of the volume of the material generated in the thermit reaction. The steel is one-third by weight, theoretically. That slag, therefore, gives up its heat to the rail head in the same way that the borax, which is so highly heated by passing the electric current through the joint that you mentioned, heats the rail head. The rail head in two or three minutes after the weld is poured, reaches the pressure welding heat. The heads are then forced together by the operation of these clamps.

Mr. Reed: How much pressure do you have to use to force those together?

Mr. Deppeler: Very little as it reaches the pressure welding temperature. The wrenches, which are about 4 ft. long (the clamps operating by hand), tend to fall of their own weight. There is practically

no resistance to the forcing of the rails together because this head area here has reached the temperature at which it is almost plastic.

So far as the finishing is concerned, we, of course, have a great deal more difficulty in the making of joints in open track than we have on the regular street railway track, because there they have power available, and we can easily design rotary grinders or reciprocating grinders to run along a track of that kind and finish the heads. On the open track we have to depend upon whatever power we can bring out. We therefore, have gasoline-driven grinders which we can use. At first, at least, we had had to adopt the German practice of hand finishing. It gives the most perfect results you could possibly imagine, and it is not as difficult as it might seem, because the upset in the rail head is very slight at the joint. It may come up ⅛ in. but it doesn't extend back very far. There is really not very much excess metal to remove. They have developed a file similar to a Vixen file with curved teeth, and another file in which there are straight teeth with a curved wave line extending through to throw the chips aside. That Vixen file is operated in a two-handle holder. Two men, one on each side of the joint, sit astraddle of the rail and pull it back and forth. It is a very short operation. It takes about 15 minutes to remove the excess metal. Another file is made to remove the excess metal from the gage face. The only finishing we need do is that on the head, the running surface, and the gage face. It is really not as difficult as it may seem, although it looks crude to those of us who are used to automatic machinery. This is true also in the shaping of the rail heads and the machining of the gap before welding. But this is very easily accomplished with modern tool steels by means of this little hand operated equipment. It is a very handy device because the shaping tool goes through between the rail heads one way, and it is then reversed and comes back and cuts in the other direction like that. I forget the exact time, but I should say it takes about 3 to 4 minutes. The two rail heads are machined down to a point an inch below the head portion. None of the processes is cumbersome at all. It is too bad we can't make them a little more automatic. We would be able to if we had power, but they won't give it to us.

Chairman Wanamaker: I might ask Mr. Deppeler has any plan been formulated for endeavoring to get test sections of track welded up in this manner?

Mr. Deppeler: That is entirely in the hands of the engineer on the railroad. We are anxious to do it. We are ready to go ahead and cooperate to any extent. His difficulty is in being a pioneer. He would rather have somebody else do the pioneering. He sees the advantage and opportunity of this work in tunnels, because without the rail joint, with its bolts and plates and everything else, he eliminates a great deal of corrosion difficulties and so on. He is willing to try it in certain cases, highway crossings and things of that kind, but he is a little bit afraid yet to be a pioneer in installing some on the main line track. Whether tests on sidetracks or seldom-used tracks would be of any value is another question because there you haven't your operating stress. You have expansion and so on, but you won't have any operating stresses to add to your expansion factor.

Chairman Wanamaker: Is there anybody else? If not, Mr. Deppeler, we thank you very kindly for this excellent presentation and will proceed to our next paper.

Mr. Peasley, you are, I believe, going to read the paper of Mr. Bergunthal of the Southern Pacific.

Discussion paper on "Reclamation of Battered and Worn Ends on Railroad Track."†

Mr. Peasley read the prepared paper of Mr. Bergunthal. (Applause.)

Mr. Peasley: Mr. Bergunthal has taken a moving picture of the entire building up of battered rail ends and joints. That will be available very shortly through the General Electric Company. If anybody cares to see the picture he can have it, complete with projector and everything, at any time he likes.

Chairman Wanamaker: We wish to thank you very much for reading Mr. Bergunthal's paper, Mr. Peasley. I regret very much that Mr. Bergunthal was unable to be here to present the paper and answer the many questions that no doubt would be asked on this subject. I feel that it was a most excellent paper, indeed, and the Southern Pacific have had apparently a great deal of experience in this work. Speaking for one railroad man I hope that it enables me to make a nice trip to California during the winter weather so that I can personally see what he has done.

Mr. Gannett, I believe you had something to say. Maybe you might go to California with me.

Mr. H. E. Gannett (Chicago, Burlington & Quincy Railroad): There are two points in particular in the paper that I should like to mention. The first one is: I hesitate a whole lot to talk about costs of building up rail ends because there are so many different conditions involved, and there aren't any data that I can see in the paper that would give any basis for estimating the prices. I just want to say one thing in this connection. If you will reverse the costs, they will be just about our experience with the cost between arc and gas welding.

The other point is that in this paper the author has practically wiped aside the acetylene welding of rail ends. I assume that action is based on quality. There certainly appears to be a discrepancy somewhere. I have here a bulletin of the American Railway Engineering Association. They made a study in connection with the oxy-acetylene welding and arc welding of rail ends. Mr. C. R. Harding, assistant to the President of the Southern Pacific, is a member of this committee. In Exhibit A, shows the hardness test on oxy-acetylene welded rail, and in every instance the rail shows that the oxy-acetylene welding was harder than the arc welding of rail ends. I assume that some of those tests were made on the Southern Pacific.

A comparison of the tests is as follows: I will read the averages of oxy-acetylene as against the arc. The average, ½ in. back from the end on top of the rail, in Brinell was: Oxy-acetylene, 259; arc welding, 229; 1 in. back of the rail joint: oxy-acetylene, 253; arc, 235; 2 in.

†Paper published in the September, 1930, issue Journal of the A. W. S.

back: oxy-acetylene, 259; arc, 237. It is practically the same all the way through.

In this article the author refers to the hardness, his attitude being that oxy-acetylene was so soft that it was inferior.

We have welded on the Burlington Railroad over a million rail ends. That is in comparison with what the paper reads. We have had no trouble that I know of that you could call real trouble. We have had occasions where the joints weren't exactly proper, more due to the operator than anything else. Individual tests that we have made on the comparative values of oxy-acetylene and arc indicate in every instance oxy-acetylene is a much better quality weld. The figures in the table put out by the sub-committee of the A. R. E. A. check almost perfectly with the figures which we obtained in our laboratory and on experiments we made on rail ends in the field.

As a matter of fact, we are using a rod that contains chromium and our Brinell hardness tests run up to 332. The best we were able to get with the arc welding rod has been 279. We have made some tests also of joints that have been welded on other railroads by a representative company. In sending them through the laboratory they advised us that the arc set up a condition of checks underneath the added metal, and that the arc weld is inferior to the oxy-acetylene weld in quality.

I do not know what experience other roads have had and would like to hear from them.

Chairman Wanamaker: Is there any other discussion of this subject? I might say that there has been a great deal of difference between different railroads, not only as to the process but as to the value of the process. It hasn't been, as near as I could learn, anywhere near universally adopted by the railroads. Apparently it behooves some of us to pay a visit to both the Burlington and the Southern Pacific to find out what is going on.

What are the reasons that it hasn't been more widely adopted? Can anybody throw a little more light on that phase of the situation? Is it because we doubt the figures and reports that individual railroads have to offer?

Mr. Gannett: Mr. Chairman, in welding up battered rail ends all you can hope to do is to make a run off across the joint. There are different types of joints to be welded, primarily four: Equal batter, unequal batter, bent joints and high and low joints. We found in actual practice in trying the arc welding process that it was necessary to weld from 40 to 60 per cent longer and farther back to be able to grind it. We put on an average deposit of metal as thin as we could, averaging 0.7 lb. to the joint. On this very same line, rail on the same track, we used the oxy-acetylene method and used only 0.07 lb. per joint, and the run off was perfect. We had to grind almost all of the arc deposited metal off in attempting to smooth the deposit and make the run off.

Chairman Wanamaker: I guess we will agree that in arc welding they have to grind almost all of it off.

Mr. Lampin (Railway Supply Company): Was any attempt made to take care of the wear under the head of the rail?

Mr. Gannett: No.

Mr. Service: Mr. Wanamaker, may I ask through you what grade of carborundum wheel gives the best results in grinding that type of weld?

Mr. Gannett: We have been using a 20-grain Norton Aluminum grinding wheel.

Chairman Wanamaker: Anybody else? If not, Mr. Peasley, and if you have no more to say, we will thank you very kindly for reading the paper.

Gentlemen, I think we have had a most interesting session and have had some most excellent papers. Is Mr. Doyle in the room? I believe he had some announcements he wanted to make before we adjourned.

Mr. Service: Do any of the members have any data as to the use of the carborundum wheels?

Chairman Wanamaker: We asked that question and we didn't get any replies. I guess nobody knows. You will have to wait until some other time, that is all.

Mr. Doyle does not happen to be about in order to close the meeting, so I am going to ask my good friend, Mr. McCune, to close this session.

Mr. McCune: I don't want to close this. I think Mr. Wanamaker should close it. As to announcements, there is only one announcement. I thought you might like to know that it has been decided that our next meeting and exhibition will take place in the city of Boston at about this same time next year.

Chairman Wanamaker: Then, gentlemen, permit me to express my sincere gratification that I was able to get here for the last day if not any sooner. I have enjoyed the privilege that was accorded to me by the officers of the American Welding Society and for your good nature in attending here while I presided I thank you very kindly.

The meeting adjourned at 1 o'clock.

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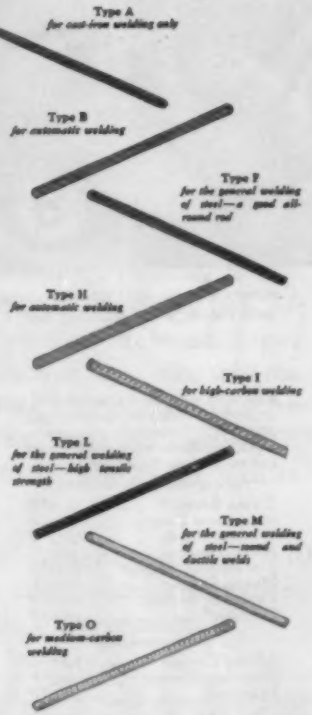

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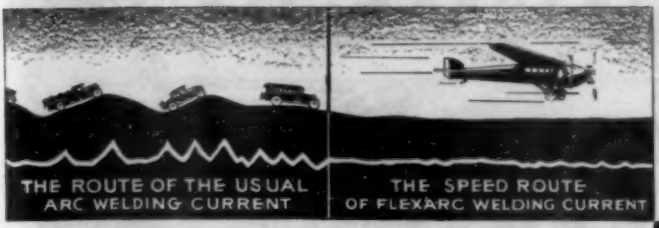

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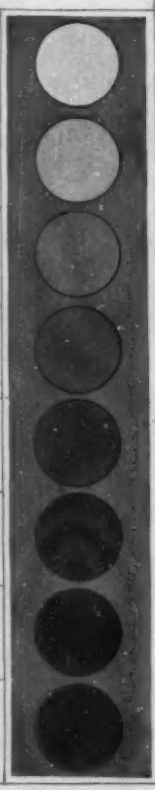
Shade No. 2		2.7 *per cent*	.5 *of one per cent*	40.3 *per cent*	Heating furnaces, welding observation, lead burning and other work involving low temperatures
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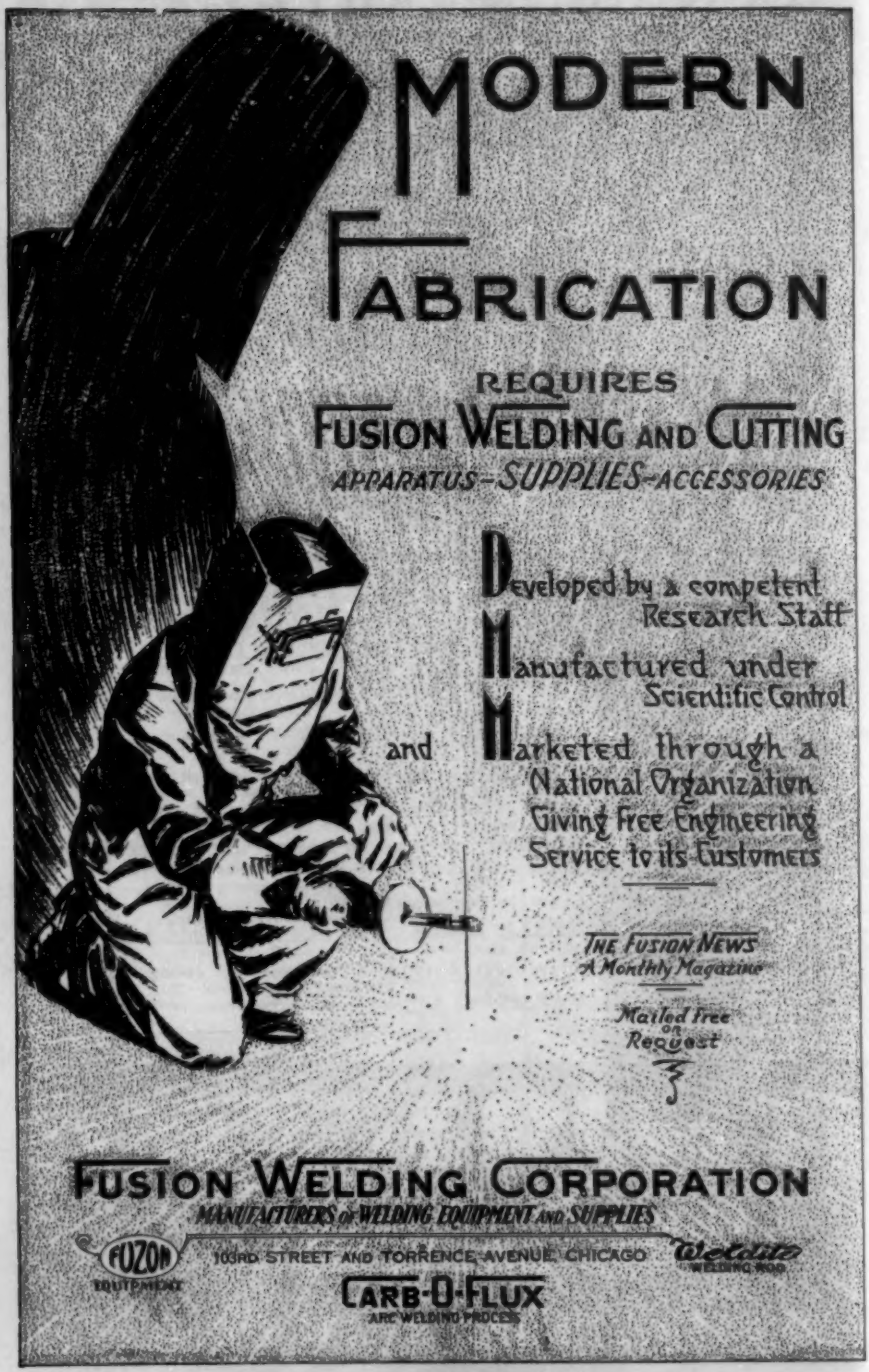

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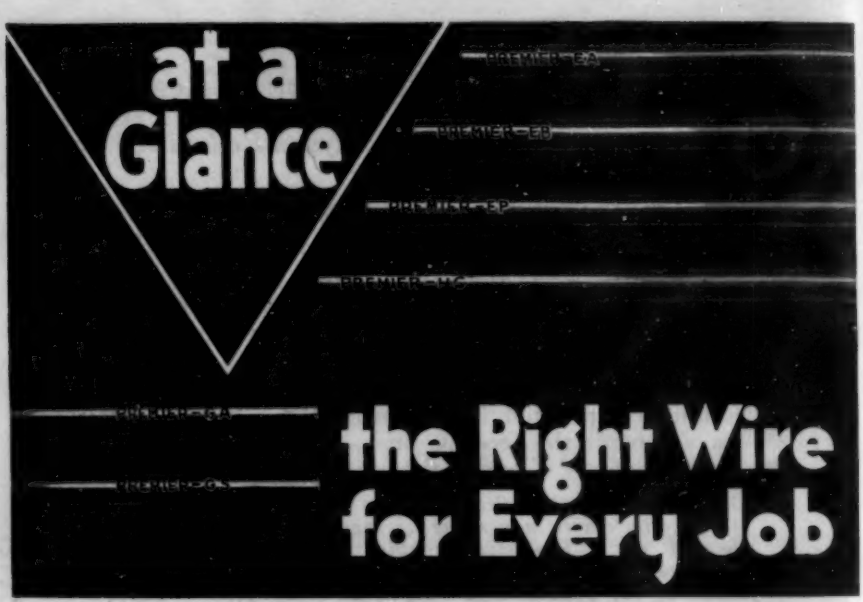

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Extract from By-Laws

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Section 2. Membership shall be divided into five classes:

Sustaining Members, being individuals or individuals delegated by corporations, firms, partnerships, etc., interested in the science and art of welding, with full rights of membership.

Annual dues..... $100.00

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Annual dues..... $20.00

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